UNITED STATES DEPARTMENT OF AGRICULTURE

FOREST SERVICE

F. A. SILCOX, CHIEF

HANDBOOK

OF

EROSION CONTROL ENGINEERING

ON THE NATIONAL FORESTS

1936

PREPARED BY

DIVISION OF ENGINEERING

T. W. NORCROSS, CHIEF

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PREFACE

Purpose and Scope of Handbook.

The purpose of this handbook is to serve as a guide in carrying on erosion control work in the national forests. It therefore emphasizes the control measures which apply to comparatively undeveloped or forested types of land rather than those for agricultural or cultivated areas.

While the great importance of vegetation as an erosion control measure is stressed, it is not within the scope of this handbook to dictate species or kinds of vegetation for specific uses. The local research office or experiment station should be called upon to advise on matters pertaining to the use of vegetation.

The greater part of the handbook deals with the design and construction of engineering structures which have proven practicable for erosion control work, and with the considerations which affect the choice and use of these structures.

Acknowledgments.

This handbook has been prepared jointly by the following men of the United States Forest Service:

E. W. Kramer, regional engineer, region 5.

A. L. Anderson, engineer, Washington office.

M. B. Arthur, hydraulic engineer, Washington office.

Much of the data and information contained in this handbook was obtained by inspection of erosion control projects and eroded areas in various parts of the United States. Forest Service projects were inspected in regions 2, 3, 4, 5, 8, and the Shelterbelt. Erosion control work by the Tennessee Valley Authority was studied in eastern and western Tennessee.

The following projects under supervision of the Soil Conservation Service were inspected: Navajo Indian Reservation in New Mexico, Gila Valley in Arizona, Santa Paula and Watsonville in California.

The authors wish to express their sincere appreciation to the following individuals and their assistants whose work, advice, and information on erosion control matters contributed largely to the preparation of this handbook:

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H. E. Reddick, regional conservator, Soil Conservation Service.

J. E. Snyder, district erosion engineer, Tennessee Valley Authority.

I. D. Wood, chief engineer, Shelterbelt project, United States Forest Service.

List of Tables

Chapter 1

THE EROSION PROBLEM ON NATIONAL FORESTS

1. Definition of Erosion.

The term erosion as used in this handbook means the rapid washing away of earth and rock by water. This includes movement from its natural state as well as transportation in well-defined channels. The most evident results of erosion are the removal of topsoil, cutting of gullies, breaking down of stream banks, depositing silt and debris on valuable land, and causing streams to become muddy. The problem of determining the proper remedy to stop rapid erosion and restore nature's balance is termed an "erosion problem."

2. Nature's Balance.

A knowledge of the relation between vegetative cover, run-off, and soil is of fundamental importance in arriving at an intelligent plan for combating erosion. It is recommended that all persons interested in erosion control problems read the book entitled "Little Waters," a study of headwater streams and other little waters, their use and relations to the land, by H. S. Person, consulting economist, with the cooperation of E. Johnston Coil, economist, and Robert T. Beall, associate economist, for Soil Conservation Service, Resettlement Administration, and Rural Electrification Administration, November 1935.

The following paragraphs have been selected from Little Waters to give a brief idea of these fundamental principles:

> The part played by forests, grasses, and other vegetative cover in the natural circulation of earth waters is of especial importance. Notwithstanding disagreement among scientists when they consider it in such aspects as influence on climate, rainfall, and stream flow of large rivers, the weight of scientific judgment is that the influence of such cover on absorption, infiltration, and ground water storage, and on regularity of the flow of creeks and small headwater streams through its influence on ground water supply, must be a dominant factor in any approach to solution of the problem caused by water and soil losses through excessive run-off. Experiments and measurements have proved that there are noteworthy differences in water and soil losses as between forest or sod lands, lands given to crop rotations, and lands given to continuous, cultivated single crops.
>
> It has been a popular belief that forests and other vegetative cover retard run-off and conserve water primarily because the humus and humified top soil absorb and hold water. These layers do have an important absorptive and holding capacity, although they seldom become completely saturated, and it is by them that the water is immediately provided which carries sustenance to the vegetative cover. But even more important is the promotion of penetration to deeper storage by these layers. The forest litter and the grass mechanically retard flow and hold back water for absorption, their coarseness promotes penetration, they serve as a filter which holds back most of the particles that might clog the soil pores, and their presence as a blanket keeps the underlying soil moist and absorbent. The humus increases porosity in a soil not only by a physical influence, but also by a chemical influence that promotes aggregation of soil particles (tilth), and by harboring worms and other soil fauna and bacteria. The roots of the trees and other vegetation open channels for penetration into the deeper ground reservoir. This function of vegetative cover to act as a mechanical retarding agent, and to keep the surface open for absorption and infiltration, is of major importance and should be kept in mind, for we shall find that it is the basis for most of the arrangements made by Man for conservation of soils and water where he has removed the vegetative cover.
>
> * * * * * * *
>
> A natural balance of retarded surface flow, underground storage, and seepage from the latter, tends to maintain a fairly regular supply of water in ponds and lakes, and of flow in streams. With this regularity there develops also a balance between water and organic life which provides food for fish and wild fowl, and through these for Man.
>
> * * * * * * *

The natural balance of land and water forces does not represent complete balance and perfectly stable relationships. It represents rather a broad frame of balance within which many variations occur. On the whole, however, the play of forces is such that there is established a maximum interplay and conservation of soils, waters, and vegetative cover.

In nature there is not, for instance, special provision for prevention of floods, either on the little waters which concern us here or on great rivers and their major tributaries. On the whole they are accepted. But under undisturbed natural arrangements floods apparently have a lower crest because of retardation of flow, and the amount of water in streams is greater during dry seasons than it otherwise would be. These arrangements may even influence the magnitude of major floods of large rivers caused by an abnormal combination of water-soaked soils and heavy precipitation on headwater areas so timed as to bring their contributory floods together into one great flood on the main stem of the drainage system. Generally, however, floods are permitted to encroach upon low-lying lands adjacent to the regular channels, and these flood plains are clothed with vegetation suitable to their environment.

3. Causes of Erosion.

Accelerated erosion is caused by disturbing the natural balance between soil, vegetative cover, and run-off. Of these three factors the one most easily disturbed is vegetative cover. This may be damaged or destroyed in many ways, of which the following are the most common:

1. Fire.
2. Overgrazing by livestock or game.
3. Logging operations.
4. Farming operations.
5. Construction of roads, dams, etc.

When the vegetative cover is damaged or removed, the amount and speed of surface run-off is increased with the result that soil is carried away and gullies are formed. Such a condition once started tends to get progressively worse.

To quote further from Little Waters:

The influence on absorption, infiltration, the groundwater, and run-off is * * * observable and measurable. Lumbering operations are immediately followed in most instances, if no other force intervenes, by rapid growth of brush and saplings. The roots, litter, and humus tend to protect the capacity for absorption and infiltration. Therefore, under the assumption that no other force intervenes, the removal of standing timber, generally speaking, has only moderate, if any, unfavorable influence on the absorption and percolating capacity of the underlying humus and soils, and on the mechanical retardation of run-off.

But other forces have been permitted to intervene. In the first place, as has been indicated, a large proportion of the land from which forest cover has been removed during the past hundred years, has been completely cleaned and made cultivable. This substitutes the influence of cultivation on absorption and percolation, * * * for the influence of forest cover.

In the second place, forest fires have been permitted to devastate cut-over lands. Slashings are especially susceptible to fire and people are careless about fires in slashings "because the valuable timber has been removed." They do not realize that elements more valuable than the timber—the litter, humus, sprouting bushes, and small trees—have not been removed by the cutting and will be destroyed by a fire. And as the fires spread to uncut areas vast damage is done by destruction of standing timber, underlying shrubs, and especially the litter and the humus under timber, in the soil, and in dried-out peat bogs.

In the third place, in forest, wood-lot, and grass areas, and in cut-over areas that would otherwise have begun to renew themselves, overgrazing has entered as a destructive force. Overgrazing destroys the young sprouts and the grass, exposes the soil to disturbance by hoofs and rain, and thereby to the invasion of erosion.

As soon as the litter and humus are removed by any of these influences, the soils which they have protected and kept open are exposed to the mechanical influence of falling and running water; the surface is sealed by the puddling rains and the action of sheet erosion; absorption and percolation diminish; and the force of the increased run-off washes the soils into the ponds and streams. This sheet erosion is eventually followed by gully erosion, the slopes are stripped in places to the underlying subsoil or rock, the area affected becomes barren waste, and most of the precipitation passes directly to the rivers and the seas. Soils and waters which might have served men are lost.

4. Basic Principles of Control.

A dense cover of vegetation with its local micro-climate, its litter layer, its humus topsoil, its soil fauna of insects, worms, and burrowing animals, is the one and only way by which erosion can readily be prevented. It follows then that when the cover—whether forest, brush, grass, or weed—has been

damaged, depleted, or removed by some external factor, its restoration will provide full and complete control. A vegetative cover and its soil check the movement of water and hence hold the soil in place by (1) preventing the rain from hitting the soil directly and so muddying it; (2) by yielding or leading into the soil clear water at low velocity; (3) by maintaining soil porosity by means of humus, abundant soil air space, and root and insect passages; (4) by maintaining a barrier against surface-water movement; and (5) by binding the soil particles together.

The first step in the restoration of vegetative cover is to prevent the continuation of the condition which brought about its destruction. The second step is to control the run-off from eroded areas so as to prevent further damage to the watershed or property below and to encourage the vegetative cover to come back, either naturally or by artificial seeding and planting.

It is in this second step that engineering is called upon to function, because the control of run-off from eroded areas calls for construction of intercepting or diversion ditches, terraces, dikes, spillways, spreading works, revetments, training walls, dams, levees, etc. These must be designed and constructed so as to render the required service as efficiently as possible. To do this, all structures must have strength and capacity to handle ordinary run-off, and the materials used must be durable enough to last as long as the structure will be needed.

Where the watershed will be revegetated in a few years the use of wood in these structures is permissible provided than when it rots out, there will be no serious loss of the soil and vegetation above them. This means that structures made of wood must be less than 2 feet in height above the gully bottom.

On arid watersheds where there is little possibility of the vegetation becoming sufficiently dense to maintain a stable condition by itself in a reasonable time, it will be necessary to construct all structures of more durable materials, such as earth, loose rock, masonry, or concrete.

5. Economic Considerations.

Before deciding upon the control measures to be taken on any given area the following economic aspects should be considered:

a. Amount of work that can be justified.

b. Will the amount of work justified under *a* be sufficient to give adequate control?

c. Amount of funds or labor available.

d. Possibility of continuance of work during successive years.

The justification required under *a* above, must be considered from three standards of value:

1. The value to the owner of this and adjacent property as it would be affected by further erosion damage. This consideration becomes especially important when the eroded area lies immediately above a highly developed area such as a city or valuable farm lands. It is also important when the streams tributary to the eroded area are valuable for water supply, irrigation, recreation, or other uses making it desirable to keep them as clear as possible.

2. The value from the standpoint of preventing floods from eroded watersheds which often cause great loss of life and property along stream and river channels through highly developed sections. If each drop of water could be sunk into the ground where it falls there would be no floods or erosion.

3. The value from the broader viewpoint of Nation-wide conservation. As certain areas of the country are abandoned to destruction, the burden of taxation and production on the remaining area becomes increasingly greater. It is generally agreed that we have already permitted the destruction of a seriously large percentage of our productive lands, and that corrective measures must be taken to prevent further damage.

Under *b* consideration must be given to the value of doing a partial job of erosion control in the event property values will not justify a complete job. In most cases it will be better to do nothing than to spend money on work that will prove ineffective.

Under *c* the availability of funds should not lead one to disregard considerations *a* and *b*. There will usually be a sufficient number of eroded areas where the work can be justified to make it unnecessary to spend money on projects of low priority.

Consideration *d* will determine to a large extent the method of control and types of structures adopted. Where work can be continued from year to year it will often be economical to construct cheaper structures which can be added to as needed, replaced, or maintained. Where there is no provision for maintenance or future work all structures must be made of materials that will last as long as the structure must function.

CHAPTER II

EROSION CONTROL MEASURES

6. Control Measures.

It must be remembered that these instructions are intended to cover all of the national forest areas in which erosion occurs. Because some measures which may be adequate in the South will be entirely unsuited to western conditions, the authors have attempted to outline the general limiting features of the various corrective measures. Do not adopt a corrective measure blindly. Read the text carefully to find out if your analysis of the specific conditions of your problem coincide with those for which the measure is intended to be used.

In the control of erosion a number of varied steps are often necessary. One or more of the following measures will be found necessary in the majority of cases:

a. Elimination of those abuses of the land or its cover that are responsible for accelerated erosion (overgrazing improper agriculture, fire, destructive logging, operation of smelters, road fills and overcasts, etc.).

b. Construct intercepting ditches on a very flat grade around the head of the eroded area, thus preventing run-off other than that from precipitation on the immediate area.

c. Drop the intercepted run-off down a gully or ditch protected by means of check dams or paving.

d. Construct a contour furrow system to reduce run-off and thus allow the vegetation to reclaim the eroded area. This system aids precipitation to percolate into the ground and thus conserves water.

e. Construct a system of terraces having protected outlets and drops.

f Break down gully banks to smooth the surface and deposit topsoil in the gully bottoms. Sometimes cut pockets or ditches into side walls to hold topsoil to permit vegetation to get rooted.

g. Plant the eroded area to some form of vegetation.

h. Cover planted area with a mulch, brush, hay, straw, or other material to hold the loose soil in place and help keep soil moist while vegetation gets started.

i. Construct brush wattles to hold a loose slope and establish a growth of vegetation.

j. Construct check dams in the gullies to prevent further cutting.

k. Construct gully-head plugs to prevent the upward progress of the gullies.

l. Construct check or soil-saving dams at such intervals and of such heights as to cause the gullies to fill up and so restore themselves.

m. Construct diversion ditches to carry run-off away from large gullies to spreading works, another channel, or other place where it can be handled.

n. Construct spreading structures below the outlets of ditches or channels to cause the run-off to spread and percolate into the ground.

o. Construct debris basins with spreading structures for storing the debris from eroded areas, and thus preventing it from getting on improved property below.

p. Construct training walls along flood channels to confine the flow and control the deposition of eroded materials.

q. Treat ravelling stream banks by sloping and planting.

r. Construct revetments or retaining walls along streams to prevent erosion of banks.

s. Construct cross-checks in channels to prevent bed erosion.

Any practicable combination of the above control measures may be used on an erosion job. The nature of the soil and vegetation, topography, amount of precipitation, and economic considerations discussed on page 3 will determine the exact method of attack.

7. Steep Slopes With Dense Soils.

Figures 1, 2, 3, and 4 show views of an eroded hillside in Claiborne County, Tenn., before and after treatment by the Tennessee Valley Authority. This is an area having a clay soil and an annual rainfall of approximately 50 inches. The slope of the gullied area is about 55 percent. Improper agricultural methods on the slope above this area and excessive grazing on the area itself led to the eroded condition. Land as steep as this should have been grazed very lightly, and should not have been subjected to concentrated run-off from the tilled land just above it. Its principal value is for growing timber and for watershed protection.

The treatment by the Tennessee Valley Authority consisted of operations *a*, *b*, *c*, *f*, *g*, and *h*, which will be discussed in detail. Logically the first step was *a*, eliminating the agricultural use which caused the condition. This not only applies to the eroded area itself but also to the land above where it is contributing excessive run-off. The next measure was *b*, to construct an intercepting ditch on almost a level grade above the eroded area. This was followed by *c*, placing check dams in one of the gullies to convert it into a channel for carrying the water from the intercepting ditch. This protected gully can best be seen in figure 4. The intercepting ditch leading to it is not visible.

With measures *a*, *b*, and *c* performed it is possible that the eroded area would have stabilized and revegetated itself with no further treatment. On an area having less run-off, flatter slope, or more porous soil this would probably have been the case. However, to speed up and make more certain the recovery of the area further treatment was given.

This consisted of *f*, breaking down the steep gully banks, thus spreading the topsoil and stabilizing the slopes of the banks. This also caused a deposit of better soil in the gully bottoms. Having broken down the gully banks and somewhat smoothed over the area, it was planted to grass and black locust (measure *g*). This was immediately followed by *h*, the covering of the planted area with brush to hold the loose soil in place and conserve moisture until the grass got started. Note in figure 2 the old fence rails which have been laid horizontally on the treated slope. They serve to hold down the mat of small brush placed over the seeded area, and being placed horizontally, they tend to check the movement of soil and water down the slope.

Figure 4 shows this same area 1 year later. Note the effectiveness of treatment. After almost 2 years the treated area can now be considered well on the way to restoration of vegetative cover.

To illustrate the use of the other operations, consider their application to this problem.

Measure *d*, contour furrow system. This would be somewhat risky here because the heavy soil would not permit rapid absorption. This locality is subject to frequent rains of high intensity, so that large ditch capacity and close spacing would be required. Due to the frequent rains, there is a good chance that the ditches would be overflowed before the banks could be stabilized by regrowth of vegetation. On a hillside as steep as this one, if water overflowed the ditch banks and poured down the slope, it would soon gather sufficient velocity to cause considerable damage, and might even start new gullies.

Measure *e*, terraces with controlled outlets. This system would function but its cost on such a steep slope would be excessive and its desirability questionable. This system is particularly adapted to areas of light slope which are to be continued under cultivation.

Measure *i*, brush wattles. This scheme is designed particularly for steep slopes of loose soil such as dams or road fills. The principal objection to its use here is the cost, which often exceeds $500 per acre. Approximately the same result was obtained in this case by seeding and covering with brush and fence rails.

Measure *j*, check dams. The construction of check dams in gullies as steep as these is never justified, except in the actual gullies which are to be used as run-off channels. As an aid to restoring vegetation in the gullies, they would be practically useless.

Measure *k*, gully-head plugs. These would not be of any value on a steep slope. They are for use almost entirely where a gully is advancing by an overfall on a comparatively level grade.

Figure 1.

Gullied Hillside in Claiborne County, Tennessee—Before Treatment.

FIGURE 2.

GULLIED HILLSIDE IN CLAIBORNE COUNTY, TENNESSEE—AFTER TREATMENT BY T. V. A.

Figure 3.

Gullied Hillside in Claiborne County, Tennessee—One Year After Treatment by T. V. A.

Figure 4.

Gullied Hillside in Claiborne County, Tennessee—One Year After Treatment by T. V. A.

Measures *l* to *s*, inclusive, soil-saving dams, diversion channels, spreading works, debris basins, training walls, revetments, etc., are for larger channels and flatter slopes. They would have no application on this immediate hillside but might be used in the valley below. Their use will be discussed in connection with other examples.

8. Steep Slopes With Porous Soils.

Figures 5 and 6 show treatment of eroded slope on the Wasatch Experimental Forest in Utah. This area has a very porous gravelly soil on a slope of approximately 40 percent. The annual precipitation is about 18 inches, coming mostly in the form of snow in the winter months. The erosion problem in this case was caused largely by the combination of overgrazing, and unusually heavy summer rains. The accumulation of run-off and debris from many such areas has resulted in devastating mud flows on highly developed agricultural areas at the foot of the mountain. Figure 7 shows the results of one of these floods at Centerville, Utah. The area shown in figures 5 and 6 lies at the head of the drainage shown in figure 7.

The treatment of the areas shown in figures 5 and 6 by the Intermountain Forest and Range Experiment Station consisted of measures *a*, *d*, *g*.

Measure *a* consisted of restricted grazing.

Measure *d*, sometimes called the Gradoni terrace system, can be seen in figure 6. These contour terraces are 3 to 4 feet wide and about 1 foot deep. They are designed to hold without overflow 1½ inches of run-off from the area tributary to each terrace. This is considered sufficient for the maximum storm and it is assumed that the stored run-off will seep into the ground before the next heavy rain. These terraces have earth cross dams spaced at 20- to 30-foot intervals, which prevent the longitudinal flow of water in the terraces and thus localize the damage if overtopped.

Measure *g*, the planting of vegetation, consisted of planting Douglas fir and ponderosa pine seedlings in the bottoms of the terraces. This will give the seedlings the maximum benefit from moisture and insure a reasonable chance of survival.

Because this area is practically at the summit of the mountain, the use of measures *b* and *c*, intercepting ditches with controlled drops, were not necessary.

On account of the porous soil and light rainfall measure *e*, terraces with protected outlets, is unnecessary.

Since the area is not badly gullied, the use of measures *f*, break down gully banks; *j*, check dams; *k*, gully-head plugs; *l*, soil-saving dams; and *m*, diversion ditches, is not required.

Measure *h*, cover planted area with brush, would have been needed if vegetation had been planted between terraces, but in this case the moisture content of the porous soil was so low that it would probably have been difficult to get satisfactory results from artificial planting between terraces.

Measure *i*, brush wattles, could have been used instead of the terraces but would have been much more expensive.

Measures *n* to *s*, inclusive, do not apply to this problem.

On a similar area not immediately above valuable property, the restriction of grazing, with possibly some planting of vegetation, is probably the only control measure that could be economically justified.

9. Gentle Slopes With Porous Soils.

Figure 8 shows an eroded area on the Navajo Indian Reservation in New Mexico which is being treated by the Soil Conservation Service. The treatment applied here is a combination of measures, *a*, restricted grazing; *m*, diversion ditches; and *n*, spreading structures.

The diversion ditch in figure 8 is indicated by arrows A, and spreading structures by B. On gentle slopes and porous soils the spreading of run-off and keeping it out of gullies is particularly effective. This not only allows the vegetation in the gullies to heal over but puts more moisture in the soil to speed up

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FIGURE 5.
CONTOUR FURROW SYSTEM ON ERODED SLOPE—WASATCH EXPERIMENTAL FOREST, UTAH.

FIGURE 6.
ERODED SLOPE—WASATCH EXPERIMENTAL FOREST, UTAH.

Figure 7.
Flood of Parrish Canyon, Centerville, Utah, 1930.

FIGURE 8.

DIVERSION DITCH AND SPREADING WORKS ON NAVAJO INDIAN RESERVATION, NEW MEXICO. BEING TREATED BY THE SOIL CONSERVATION SERVICE.

the growth of the vegetation. On an arid area such as this the vegetative growth is necessarily slow and sparse and any measures that tend to conserve the water are particularly beneficial.

Consider the application of other control measures to this area:

Measures *b* and *c*, intercepting ditches and controlled drops, could have been applied in conjunction with *m* and *n* if considered necessary.

Measure *d*, contour furrow system, would have been effective but its cost would be too great for an area having such low value. Less expensive methods, such as measure *m*, are available to spread the run-off to increase absorption on moderately sloped areas like this.

Measure *e*, terraces with protected outlets and drops, would also be too expensive and in this case would not be as desirable as the contour furrow type, since it is desirable to prevent loss of precipitation by run-off.

Measure *f*, break down gully banks, is probably too expensive for the benefit derived, considering the value of the area and the fact that no planting was to be done.

Measure *g*, planting vegetation, would probably not be very successful because of the arid conditions. A few plants of selected species would survive if planted so as to get the maximum benefit from rainfall and run-off.

Measure *h*, cover planted area with brush. If planting had been done measure *h* would probably have helped get the vegetation started.

Measures *j* and *k*, construction of check dams and gully-head plugs, could have been done but would not have been of much value toward reestablishing vegetation. It would have prevented further gully cutting but not the excessive run-off from areas adjacent to the gullies which is really more important. Furthermore, the expense of constructing check dams could probably not be justified on this area.

Measure *l*, soil-saving dams at such intervals and of such heights as to cause the gullies to fill up and so restore themselves, could not be justified in this case as the benefit to be derived from filling the gullies would not be great enough to cover the expense.

10. Gentle Slopes With Dense Soils.

Gentle slopes and dense soils are typical of agricultural areas where measure *e*, terraces with protected outlets, is commonly applied.

Figure 9 shows a system of terraces with permanent masonry checks as outlets for each terrace. This system will permit the continued cultivation of the field and prevent excessive erosion. Since such a system must function as long as the fields are kept in cultivation it is necessary to construct the checks of permanent material such as rubble masonry or concrete.

For other than agricultural use, any of the other control measures listed under section 6 are applicable.

If the area is badly gullied, as the Borgsmiller Gully, Jackson County, Ill., shown in figure 10, measures *a*, restricting use of land; *f*, breaking down gully banks; and *g*, planting eroded areas, will often be sufficient. In this case it was also necessary to employ measure *j* in the form of low check dams to retain soil in the gully bottom and allow the vegetation to start. Figure 11 shows the Borgsmiller Gully immediately after the above measures had been applied. Figure 12 shows the results of these measures 1 year later.

For an area in the first stages of erosion, measure *a* together with *g* alone may be sufficient to prevent further erosion and cause the return of vegetative cover.

11. Restoration or the Filling of Gullies.

Gullies are the evidence of advanced stages of erosion. The excessive erosion itself can usually be controlled and vegetation restored without raising the gully floors to the ground level.

In cases where large gullies have lowered the water table, as illustrated by figure 13, and thus contributed to the depletion of vegetative cover, or where the use of the ground will otherwise justify the expense, steps may be taken to restore gullies to approximately their normal level. This is measure

FIGURE 9.
GENTLE SLOPE—DENSE SOIL AGRICULTURAL TERRACES NEAR RUSH SPRING, OKLAHOMA.

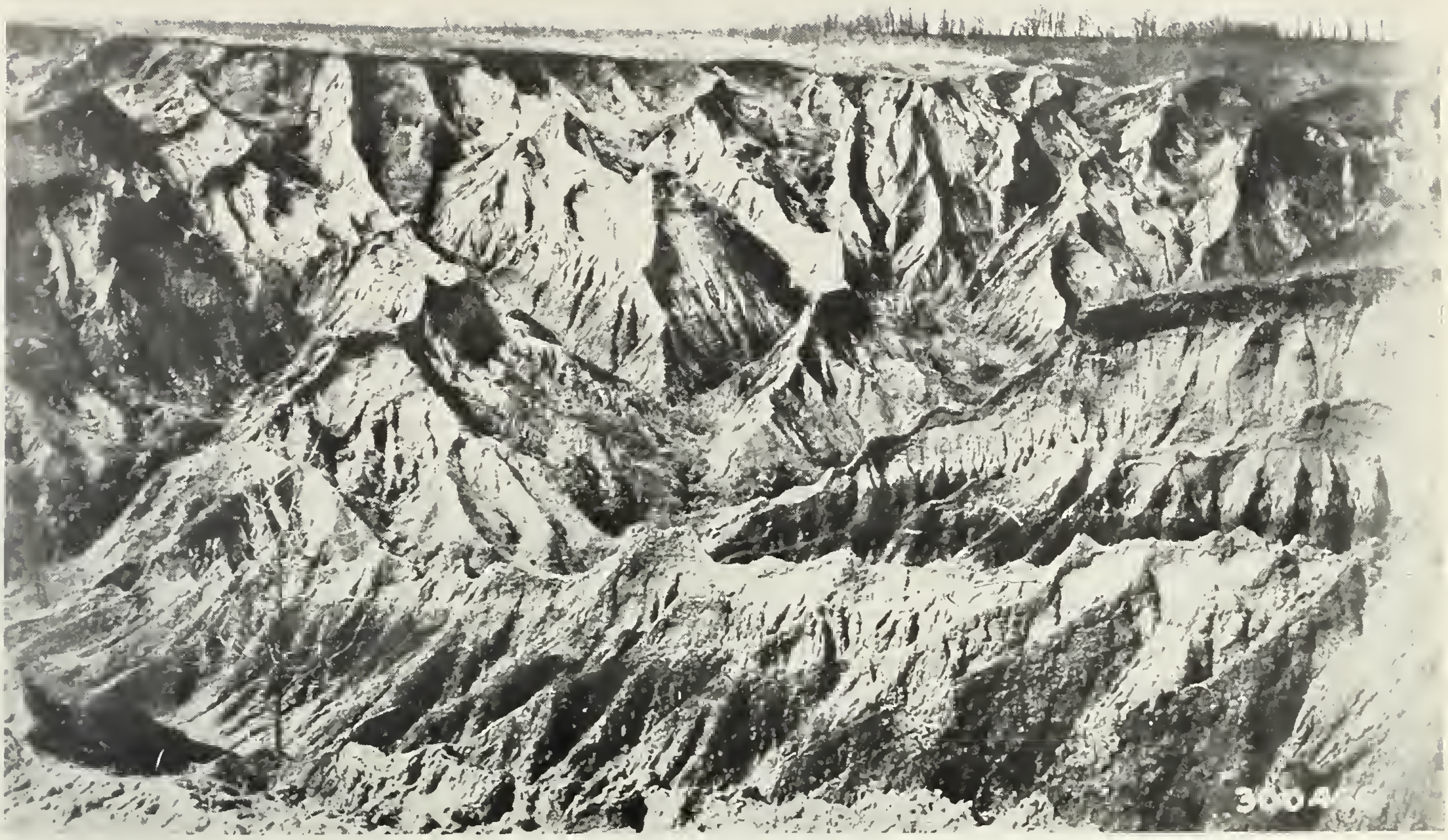


FIGURE 10.

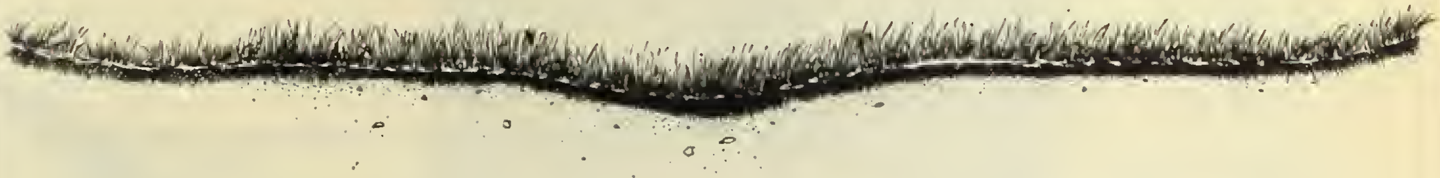
THE BORGSMILLER GULLY, MURPHYSBORO, ILLINOIS, EARLY SPRING, 1934—READY TO START WORK.

FIGURE 11.

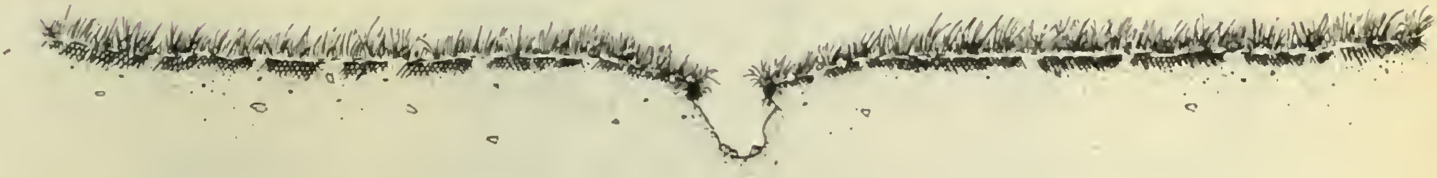
THE BORGSMILLER GULLY, MURPHYSBORO, ILLINOIS, LATE SPRING, 1934—BANKS WORKED DOWN AND PLANTED WITH BLACK LOCUST TREES AND LESPEDEZA.

FIGURE 12.

THE BORGSMILLER GULLY, MURPHYSBORO, ILLINOIS, LATE SPRING, 1935—ONE YEAR AFTER BEING PLANTED. NOW FULLY HEALED BY TREES AND LESPEDEZA.



Trough of valley in natural state. Protected by heavy sod.



Gully formed in trough of valley by increase in rate of runoff and decline of sod cover.

Second-stage causing depletion of vegetable cover in valley and lowering of water table. Sage brush is replacing grass.

Overfall - Gully depth "A" increases to depth "B"

FIGURE 13

CROSS SECTIONS SHOWING
THE SUCCESSIVE STAGES IN THE
FORMATION OF A GULLY

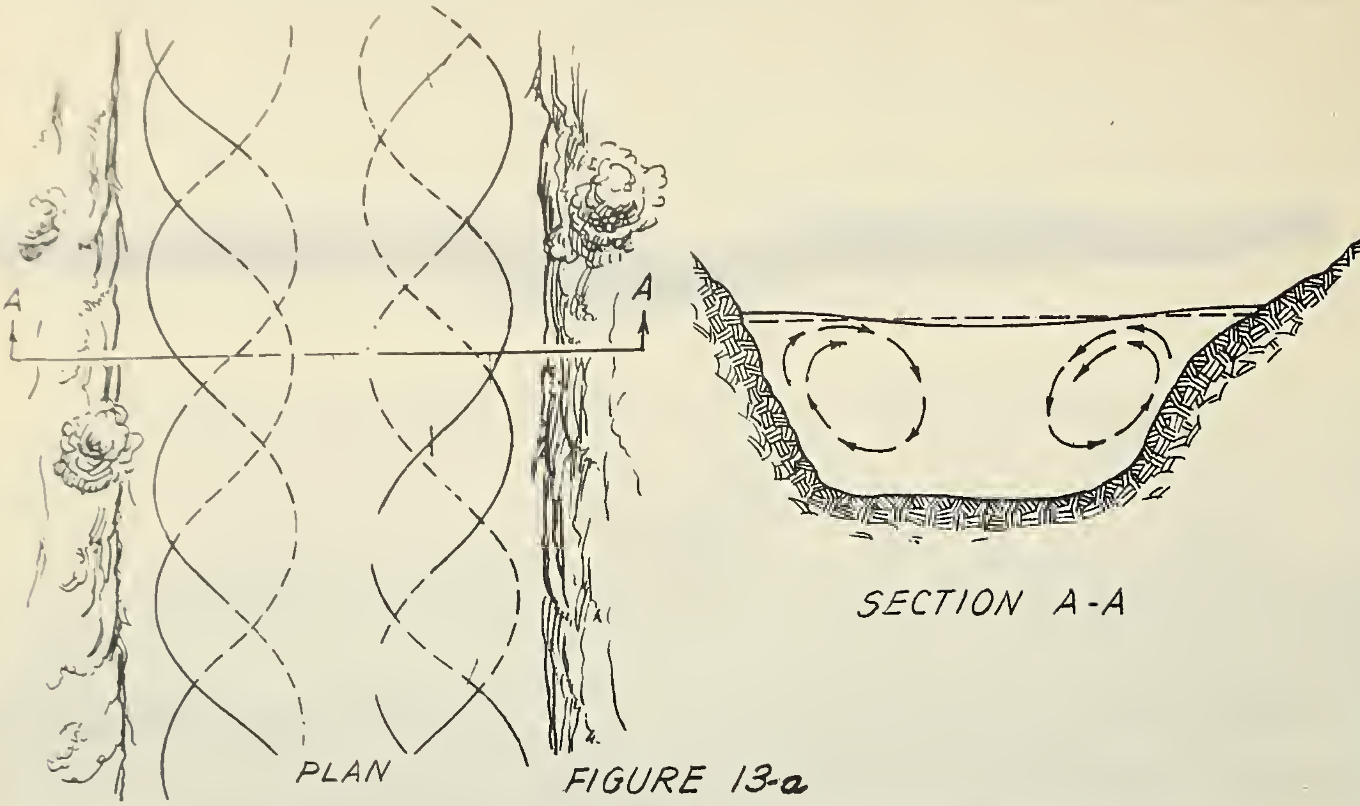


FIGURE 13-a
TRANSVERSE CURRENTS IN A STRAIGHT CHANNEL
OF UNIFORM CROSS SECTION

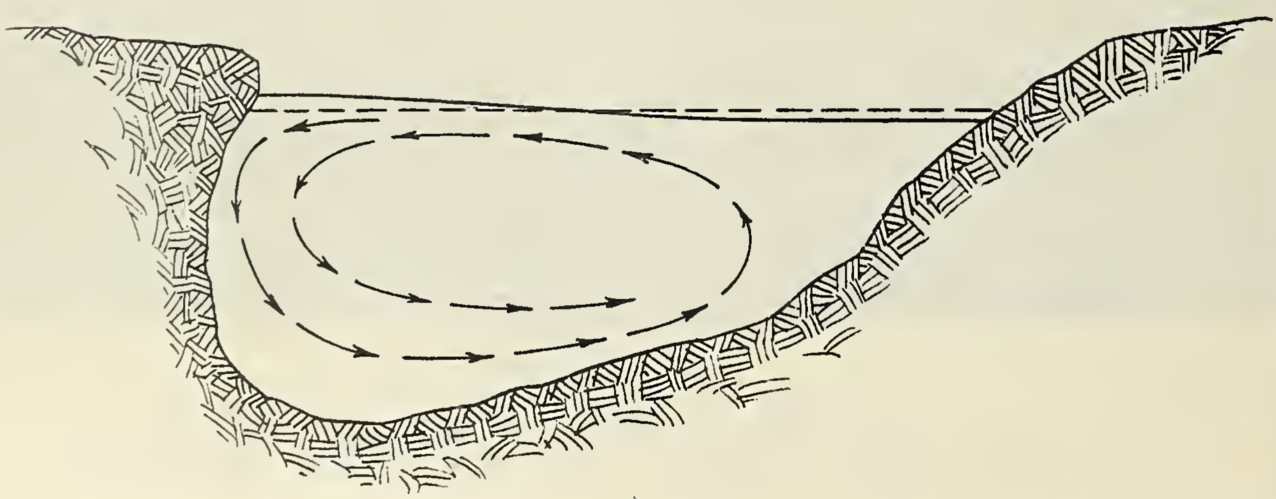


FIGURE 13-b
TYPICAL CROSS SECTION
SHOWING SPIRAL CURRENT MOVEMENT AT RIVER BEND

FIGURE 14.

DEBRIS BASIN NEAR SALT LAKE CITY, UTAH—CONSTRUCTED BY UNITED STATES FOREST SERVICE.

1 as described under Section 8. There are two general methods of accomplishing this result. One is to construction the dams of permanent material to the full height that it is desired to raise the gully. The other method is to construct a series of low temporary dams and later construct other similar dams on the silt deposits, continuing this process from year to year until the gully is filled to the desired height.

The possibility of continuance of funds for several years will determine whether the second of these methods can be adopted. It will usually be the cheaper of the two.

12. Mud and Debris Flows.

Due to denuded areas on some watersheds, heavy seasonal rains cause large quantities of eroded material to flow from the steep canyons and spread over the flood cones at their mouths. Because these floods of debris often cover valuable land, railroads, and highways, it is necessary to construct works to control them and check their spread until such time as the vegetation on the watershed becomes dense enough to prevent their recurrence. See figure 7.

Figure 14 shows a typical debris-basin development at the mouth of a small canyon near Salt Lake City, Utah. The component parts of this work are indicated by letters on the picture as follows:

A, the earth dike.
B, the masonry spillway.
C, spreading structures within the basin to cause the flood to spread and deposit part of its load at the upper end of the basin.
D, masonry openings through dike for irrigation ditches. These are provided with gates which can be raised as the debris deposit raises behind the dike.

The earth dike A was simply pushed up to a height of 10 feet by tractors equipped with bulldozers. No attempt was made to roll, dampen or otherwise compact the dike as it will ordinarily not be required to hold any appreciable amount of water. The floods coming behind it will consist largely of earth and rock with just enough water to make it flow.

The masonry spillway is designed on the same principle as any masonry dam. See section 37 for details on masonry spillway construction.

The spreading structures are constructed of masonry in a V-shape with the points upstream. The points of the structures are cemented while the wings are of dry masonry. See section 41 for further details.

The openings for irrigation ditches are placed where existing ditches were located. They have a gate which can be closed to prevent floodwaters from getting into the ditch. The gates are constructed so they can be raised as the debris level rises inside of the dike.

13. Channel Control.

A. The Peculiarities of Stream Flow:

Gravity is the motivating force behind the flow of water, causing it to pass from high to lower elevations, or to use the common expression, to flow down hill. When the water surface drops to a lower elevation, the energy equivalent to the drop in elevation, or head, is converted to velocity. The fixed relation between head and the velocity which it will produce is represented by the equation $v = \sqrt{2gh}$, where v is the average velocity in feet per sedond, g is the acceleration of gravity (32.2) and h is

the loss of head in feet. Conversely, $h = \frac{v^2}{2g}$, $\underline{h}$ representing the head which will produce a certain velocity, $\underline{v}$. Therefore, any known velocity $\underline{v}$, can be converted back to the head, $\underline{h}$, which caused that velocity, in which case $\underline{h}$ is known as the velocity-head for that particular condition. Another force to be considered is that of friction, for there is a certain amount of energy lost in overcoming the friction of water against the sides of the channel and within itself, as described later. At any point in the channel, the drop in head from the initial point is equal to the increase in velocity head plus the head lost in friction in the interval.

It is of particular importance in river hydraulics to recognize the fact that water does not move forward in uniform, parallel layers, but instead is subject to regular pulsations, combined with very irregular eddy and roller motions. The cross-sectional area and the velocity change continually, but mathematically every change in velocity must correspond to a change in surface elevation. In any particular reach in which the cross-section has a trough or U-shaped form, the water flows more rapidly in the middle and at the surface, and more slowly at the shores and along the bottom. Due to the friction of the fast moving particles in the middle against the slower moving particles on the outside, the flow is attracted from the shores toward the center and continually moves from the zone of slow edge velocities to the zone of more rapid center velocities. Because of this motion, it is evident that a transverse gradient exists, and the water surface at the middle of a river must be lower than at the edges of straight reaches.

This condition holds not only when the quantity of flow of water is constant, but also when the stage is falling. The condition is reversed for a rising stage. The only significance this has to our problem is to emphasize the fact that in river flow there is no such thing as parallel or laminar flow, and that even straight reaches of river channel are subject to the erosive action of transverse currents, as shown in Figure 13a.

If, as is frequently the case, the material on one bank is more erosible than the other, the once uniform section is cut away at that bank, introducing a bend in the channel which results in a spiral motion of the water. The transverse movement becomes increasingly greater, and the inertia of the moving water around the bend raises the water surface on the outer or concave side of the bend, thus further aggravating the spiral motion. The superelevation of the water influences the velocity and direction of flow around the curve, and it follows that water must flow continually from top to bottom at the concave shore, as illustrated in Figure 13b. It is evident that after a bend has once started,there is a constant tendency for the curvature to become greater.

The control of streams which are subject to large periodic flood flows and which have unstable erosible soil for their bed and banks is further complicated by the presence of a variable amount of solid matter that is carried by the water. This solid matter may be divided into two types,

1. Suspended matter, which travels great distances suspended in the flowing water, and which settles only when the velocity decreases, or when the distribution of velocity changes.
2. Detritus, or bed load, which moves by sliding, rolling, and jumping along the bottom of the channel, and which may also travel great distances.

Their laws of occurence are similar, and it is not usually possible to distinguish one from the other after the two types have been deposited. However, the source of the detritus is more often the upper part of the stream, where it comes from the weathering and erosion of the mountain slopes, and generally contains the coarser and more abrasive particles. The finer particles that go into suspension are more often acquired from the lower reaches. It is the presence of this solid matter that makes it possible to so direct and control the stream currents as to build up protecting bars and deposits which prevent further damage to the banks.

The amount of solid matter carried by a stream varies according to the stage. The higher the flood stage the greater will be the velocity and the transporting power of the water. A measure of the transporting force of streams in which the width is more than 30 times the depth may be computed from the formula:

$$F = 62.5 \, d \, s \qquad (1)$$

in which F is the transporting force in pounds per sq. ft. d is the depth of the water, in feet, and s is the slope of the water surface expressed as the ratio of vertical drop to horizontal distance.

For narrower streams a more exact determination of the transporting force may be made by using the hydraulic radius of the section in place of the depth in formula (1).

Table I gives the transporting force, called the limiting force, required to start movement of various kinds and sizes of detritus. The transporting force at which moving sediment begins to settle is about 70% of the limiting force at which it begins to move.

Table I
Limiting Transporting Force of Detritus

Kind of Detritus	Size of grains	Screen Size or diameter	Transporting Force in lbs. / sq. feet
Clayey Soil		passing #40	0.2 to 0.25
Sand	0.20 to 0.40 mm.	#75 to #40	0.04
"	0.40 to 1.00 mm.	#40 to #18	0.05 to 0.06
"	graded up to 2.00 mm.	Passing #10	0.08
Gravel	0.5 to 1.5 cm.	#4 to 9/16"	0.26
Coarse gravel	4.0 to 5.0 cm.	1-1/2" to 2"	1.0
Flat limestone chips	1 to 2 cm. thick,)	3/8" t 3/4"	1.15
	4 to 6 cm. long)	1-1/2" to 2-1/4"	

Another factor, the amount of which cannot be measured, has much influence on the transporting ability of flowing water. This factor is the turbulence, for upward currents which accompany it tend to keep soil particles in the suspended state. Clear water is more erosive than turbid water because it can gather new particles to transport, whereas turbid water has already acquired its load of detritus.

Structures for the control of river currents should not be built until after an analysis has been made of the hydraulic reasons for the particular fault which must be corrected, and of the hydraulic action which will take place after the structures are in place. It must be borne in mind that regardless of the structures built, there will be no reduction in the quantity of water to be passed, and that there is a direct relation between the quantity of water, its cross-sectional area, and its average velocity. Any obstruction which reduces the area will be unavoidably followed by a proportionate increase in the average velocity, which may so increase the transporting force as to start troublesome erosion at previously stable points in the stream.

B. Protection Methods.

The most efficient method of channel bank protection is one which guides rather than opposes the course of the river, and results in the formation of accretions in front of the caving banks and other vulnerable spots. If the river currents can be induced to do the work by structures made from materials provided by nature, the cost need not be great. The problem is reduced to the choice of the type of structure, its proper location, construction and maintenance. Obstructions placed in the bed of a river to

build up bars as a protection against erosion are useful in slow-moving, heavily silted streams where the structures will not cause a detrimental increase in the water velocity. Their usual effect in swift streams is to cause erosion of the bank opposite the structure because of increased current velocities, or to increase scour on the channel bottom, which will ultimately undermine and destroy the obstruction.

If the damage is being done on straight reaches of the river it will ordinarily be necessary to protect both banks, the layout of the structures being guided by the location of the troublesome spots. Protection will be needed only on the concave side of curves. The toe of the bank will be subject to the most severe cutting action and must therefore have better protection than the higher parts of the bank.

Three general types of channel protection are:

1. Slope protection.
2. Spur dikes.
3. Continuous dikes.

1. Slope protection. Riprap is the simplest kind of slope protection to build. It consists of quarry stone placed on the slope from top to bottom, to withstand the erosive action of the water and is most commonly used for road or railroad fill slopes adjacent to streams where the water velocities are not excessive. The slope of the embankment under the riprap must be flat enough to be stable when saturated with water. The purpose of the rock riprap is to give the additional protection needed to withstand the current.

The rock is usually dumped from cars or trucks at the top of the bank. The structure is built up from the bottom, where the deposit will be the thickest and the most useful because the toe of the embankment is where the greatest protection is needed. However, ordinary riprapping is effective only for velocities of moderate severity in straight or moderately curving channels. Riprap made of large pieces of rock placed individually by derrick may resist very strong currents, as shown in Table II.

Table II
Allowable Tractive Force of Protection Elements

Kind of Protection	Tractive Force
Sod revetment (short periods of attach)	0.4 lbs. / sq. ft.
Fascine Paving	1.4
Well laid stone paving 1 ft. thick	3.3
Random riprap (stones 100 to 1000 lbs.)	5.1
Rock or fascine filled crib or piles	12.3
Rockfilled timber cribs on rock foundation	30.0

Tractive forces greater than 30 lbs. per sq. ft. can be withstood permanently only by heavy, well founded concrete or massive masonry structures.

Where sufficient rock is not available for riprap, a mat of brush, bound with wire and weighted with rocks or other ballast, may be used. Adequate protection against undercutting at the toe of the slope is essential. Figure 15 shows details of one type of brush paving known as the fascine mattress. For extreme conditions, concrete or other more permanent massive masonry structures are required, but they will be relatively expensive.

The fascine mat is woven from bundles of willows or other brush which grows in abundance along many rivers. The individual saplings should be at least 14 feet long,

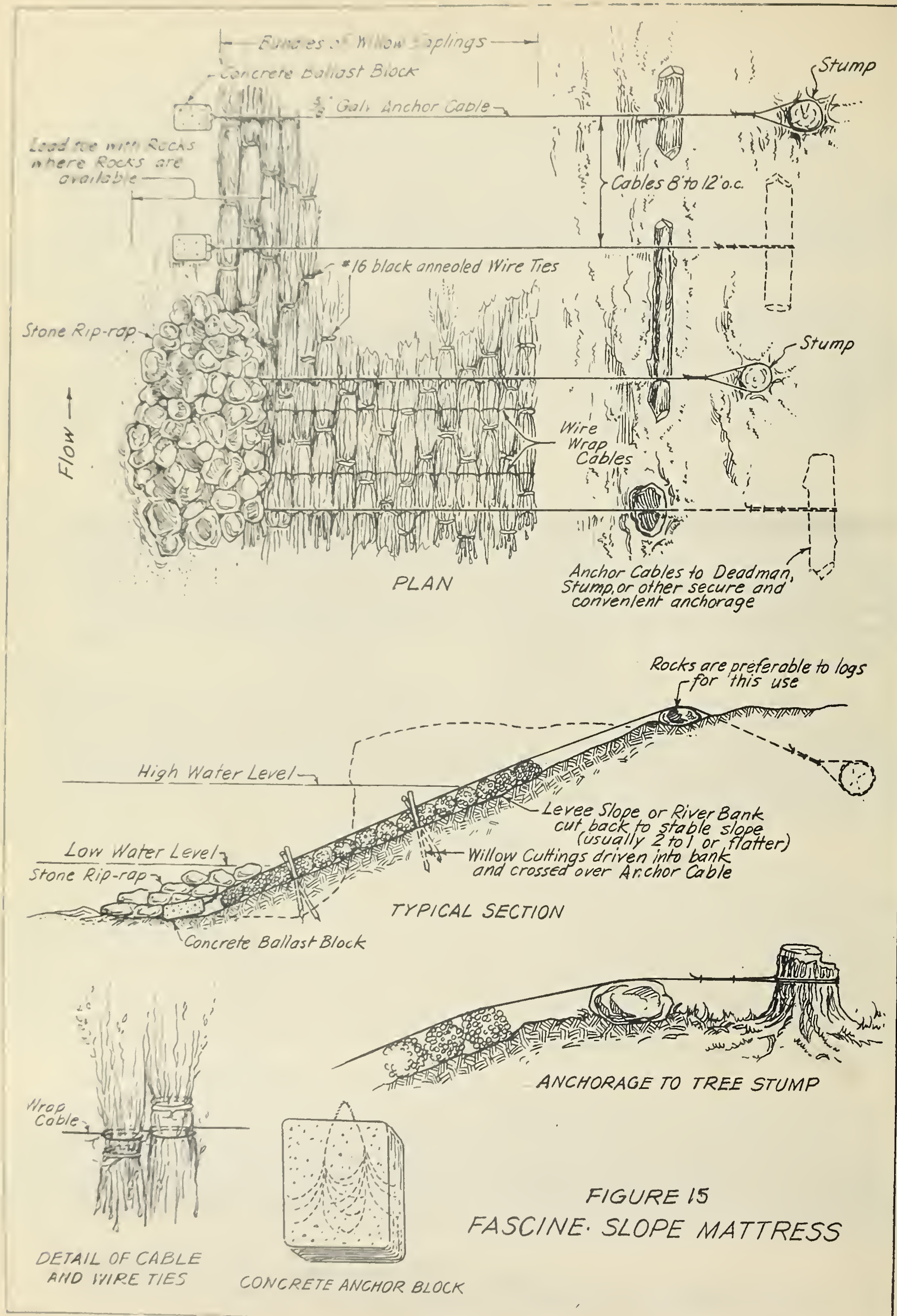


FIGURE 15
FASCINE· SLOPE MATTRESS

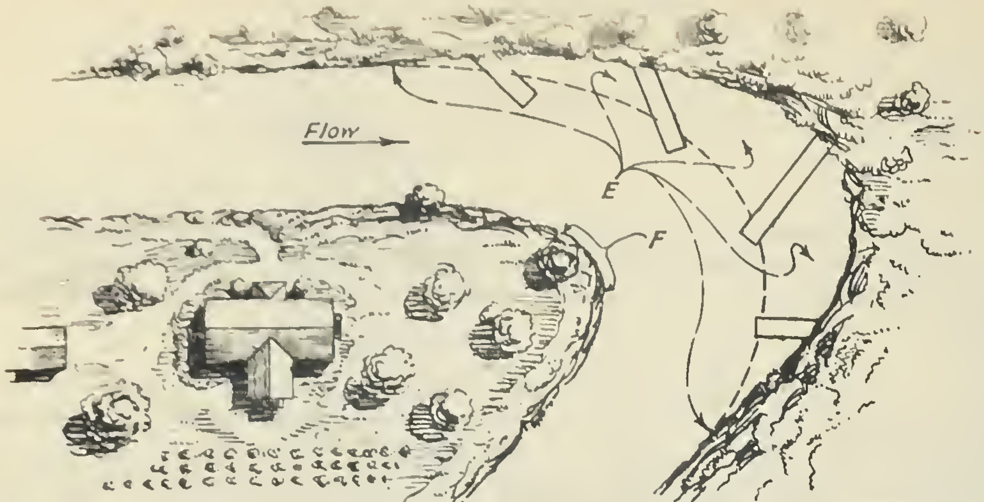
and longer if possible. They are bound into bundles about 12 inches in diameter at the butt, using black annealed wire not smaller than No. 16 gauge. There should be not less than three bands of wire, uniformly spaced at 3-foot intervals, beginning one foot from the butt end of the bundles.

The mattress is built, either floating over the final position, or supported on a barge with sloping ways on the shoreward side. Fascines, with butts upstream and overlapping the tips about two feet, are placed side by side, and bound closely together with flexible galvanized wire cable, usually one-fourth inch in diameter for small projects. Each loop of the cable is held in place with a tie of No. 12 wire. For large mats, or in swift currents, additional rigidity can be secured by weaving poles in with the cables, at right angles with the fascines. When fabricated, the mat is sunk to the bottom by loading it with rock, or with a concrete block ballast and anchor cable arrangement as shown in Figure 15. At least 14 pounds of ballast per square foot of mattress will be required. Anchor cables may be secured to dead men, stumps, or other available anchorage along the bank, the spacing depending upon the anchorage available. The spacing should not exceed 12 feet, and each concrete ballast block must be heavy enough to hold down the intervening mattress area.

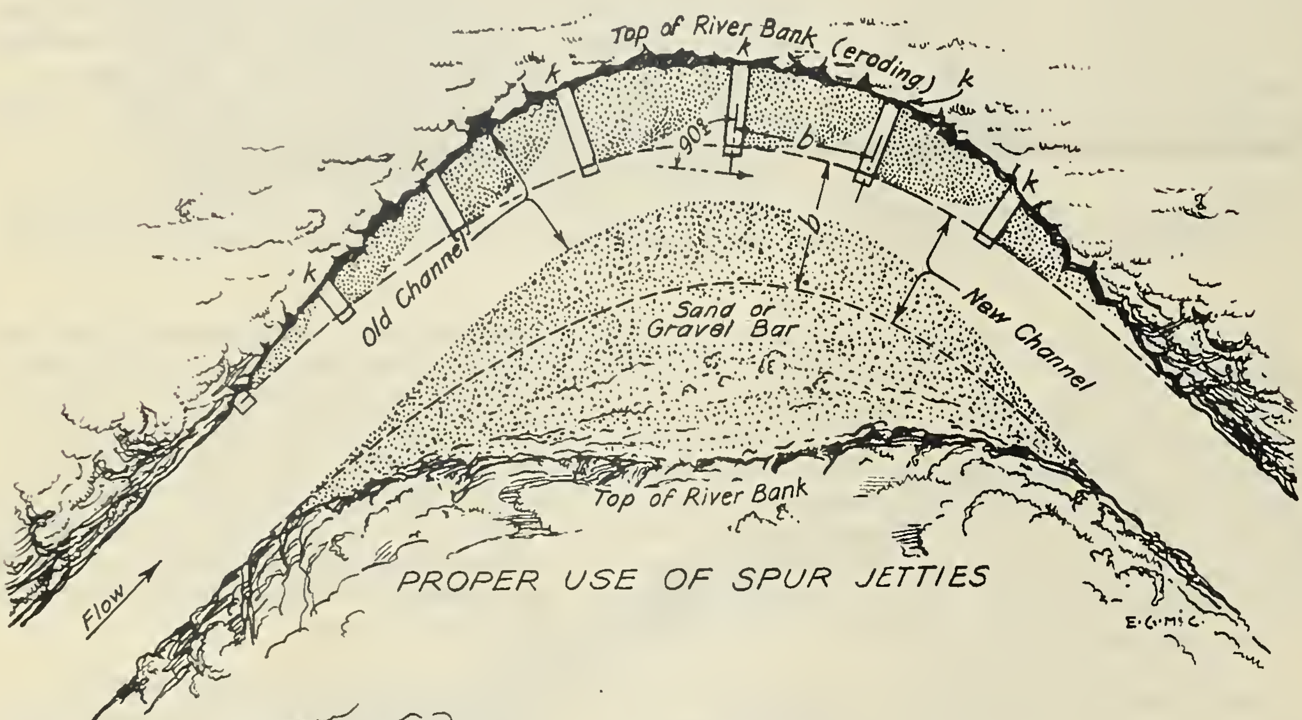
Liberal use should be made of stakes and wattles of willow cuttings in all the foregoing schemes, as growing willows will add greatly to the effectiveness of all of them.

2. Spur dikes. Dikes or jetties are built to divert the current away from vulnerable areas so that silt and sand bars will be created on the sheltered side of the structures. The location of the jetties and the methods of construction are of equal importance. It is also essential that the dikes and the bars behind them be planted to willows or similar growth to make the stabilization permanent. In planning this type of protection it must be remembered that the jetty, although not water tight, obstructs the channel because it reduces the effective area and is the cause of increased velocity in the unobstructed part of the channel. In some cases it causes vital changes in the direction of flow. Both increased velocity and change of direction of the current may become new sources of trouble at other points along the stream.

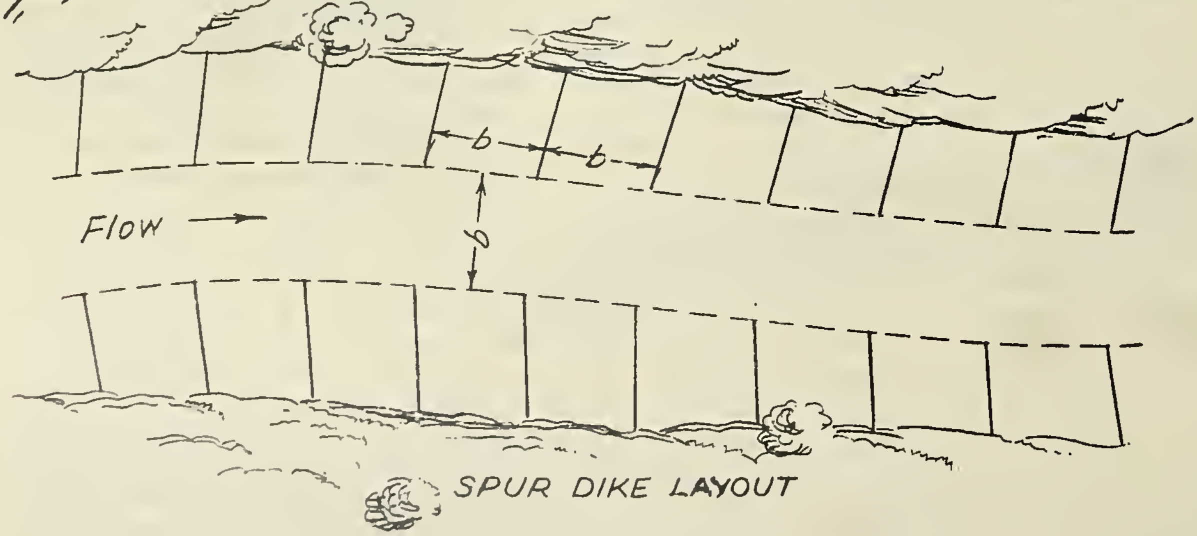
Consider the example of a channel with a sharp bend and which flows bank full during normal and flood stages. If both banks are composed of erosible material, it will seldom be advisable to build spur jetties to protect the concave side, because they will occupy too much of the cross-section area, and will direct the current to the convex side where the erosion may be continued. Slope paving or continuous dikes would be more suitable for this condition. However, there are many cases where the concave bank has been eroded so far back that there is excess width between banks. In this case, spur jetties will cause a readjustment of the flow within the original banks and will be the most effective corrective measure available. Figure 16 illustrates this point. The upper diagram shows the unfavorable condition, and the center diagram shows the favorable condition. In the upper diagram, the arrows at E point to the area in which the concave bank has been cutting away. The bank at F is as high as the other side, but has been stabilized by vegetation, without help, because the force of the current is directed away from it. However, if the channel is obstructed by jetties on the concave side, the current will be directed toward area F with greater force and the trouble at E may be transferred to area F where considerable damage may be done. The center diagram illustrates the condition in which the loss on the concave side, K, has continued for so long that there is a wide expanse between the banks, part of which is occupied by a gravel bar that is flooded during high water periods. In this case spur jetties will cause a shift from the old channel to some such position as that marked "new channel", and will hold it as long as the concave bank protection stays effective.



IMPROPER USE OF SPUR JETTIES

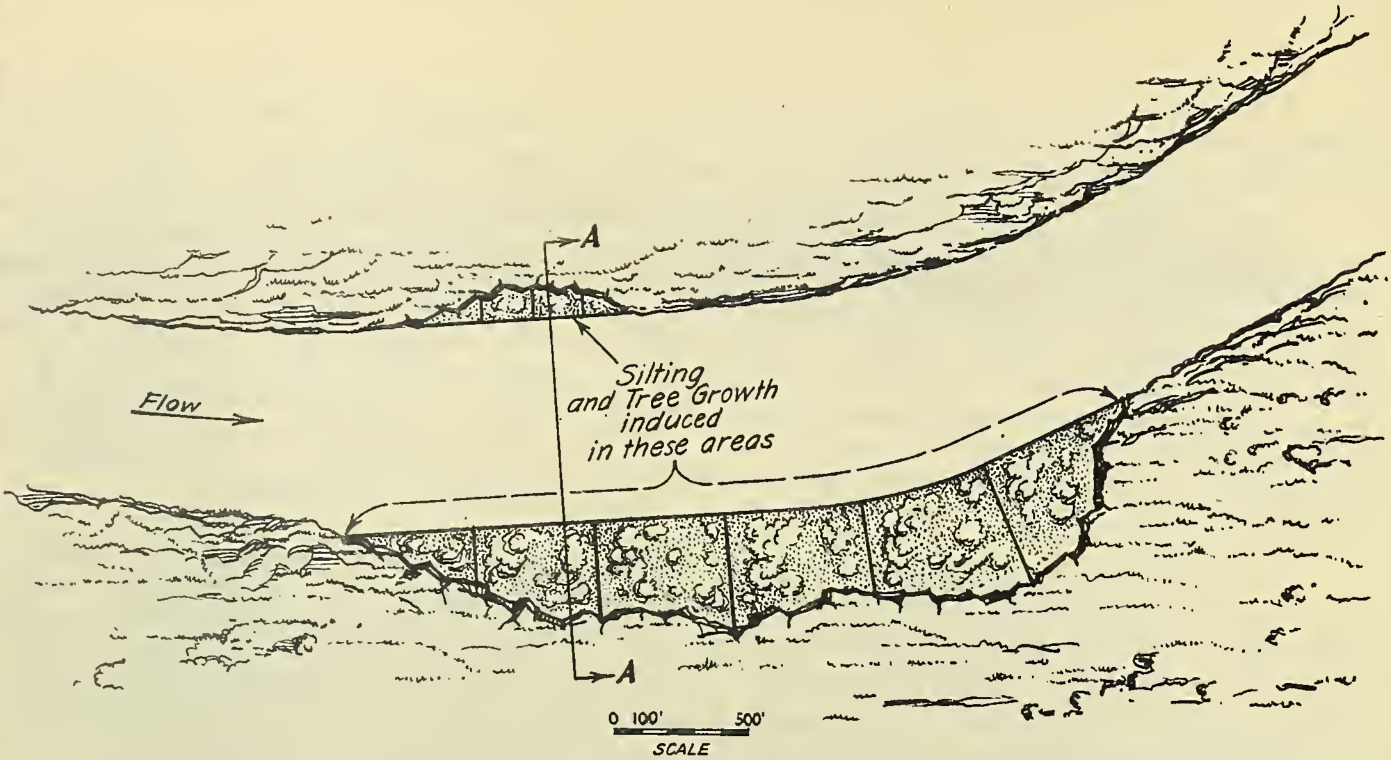


PROPER USE OF SPUR JETTIES

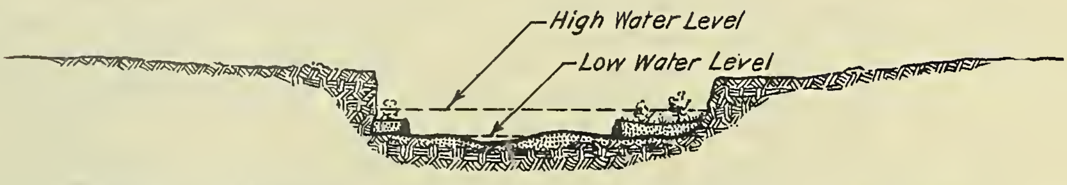


SPUR DIKE LAYOUT

FIGURE 16
USE OF SPUR JETTIES

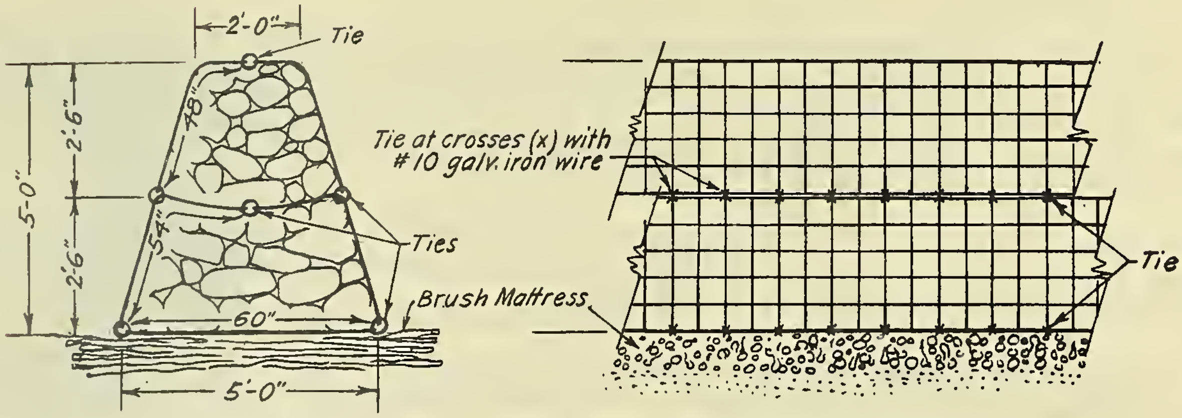


PLAN



Streambed composed of shifting bars of silt and fine sand

SECTION A–A
(Vertical Scale exaggerated)



SECTION — SIDE ELEVATION

WIRE BOUND ROCK JETTY

Wire envelope to be 6 ga. 6"×6" electric welded fence wire, using 48", 54", and 60" widths as required. For dikes of different heights, use proportionate dimensions with whatever widths of wire are required.

In completing the bottom section, the rock fill surface should be 3" lower in the middle than at the edges, and the wire drawn tightly together. When rock for the top section is added, the sag takes up the remaining slack in the bottom wire, giving a tighter finished job.

FIGURE 17

GENERAL PLAN OF
CHANNEL CONTROL SYSTEM
FOR LOW VELOCITY RIVERS
WITH SHIFTING SILT BOTTOM

Liberal use of shrubs and trees which will build up strong root systems are vital to any enduring protection scheme.

There is no fixed rule which determines the spacing between the individual spurs, or the angle which they make with the direction of the current. The factors depend on the combination of conditions at each location. In general, on concave curves, the spur should be at right angles to the thread of the stream, as shown in the lower diagram of Figure 16. This tends to prevent longitudinal currents along the face of the spur, and water which flows over the top of the spur is not directed toward the river bank. A spacing between spurs approximately equal to the width of the confined river channel will usually be sufficiently close to cause the desired silting action as rapidly as is necessary. Closer spacing will tend to increase the rate of deposit, but is seldom justifiable because of the increased cost of the additional structures.

It has been found that the rate of sedimentation on channels where the curvature is slight has been more rapid when the spurs are turned so that the shore end is somewhat downstream from the outer end. The advantages of this alignment are that the current action along the spur face is less severe, and the direction of the overflow current during high water is away from the stream bank. However, the undercutting action at the head of the spur is more severe, and therefore more protection against this action is required. For all conditions, it is important that the foundations of the jetties be carried down below possible scour level.

A cross section of a rock and wire basket jetty is shown in Figure 17. The base is laid on a mat of loose brush, which should have a compacted thickness of about eight inches and project from nine to twelve inches at each side. Details of wrapping the wire are shown in Figure 17. No attempt should be made to make the jetty impervious, because it is not built to withstand water pressure and the water depth should be the same on both sides. The value of the jetty lies in the fact that it retards the water velocity to the point where much of the suspended silt is deposited, building up bars where trees and brush can be induced to grow, either naturally or through planting. The stimulation of brush and tree growth should be the object of all of this protective work, so that after the structures have rotted away or otherwise failed, the corrective work will still endure.

Wire bound dikes should not be used along rivers which carry a bed load of sand, gravel, or rock during flood flows. The abrasive action of these materials on the wire soon wears it through and the loose rock fill spills into the river, causing failure of the dike. If the bed load contains more than 20 percent of sharp stones retained on the #10 screen the abrasive action will be harmful.

For general use, the timber pile and fascine jetty type of construction will be found very satisfactory. If cutting occurs along the face, the jetties are protected against failure by the penetration of the piles.

The piles are driven in double rows with a space of 3 feet or more between rows, and tied together at the top with cable. The cable is secured to the pile top with heavy staples. The cable should be 3/8 inch diameter (galvanized) for small dikes, increasing to 1/2 inch for more severe usage. The space between the two rows of piles is filled with willow fascines, the relation between the pile spacing and the fascine length being such that each bundle will be retained by at least three piles. The longitudinal pile spacing should not be more than one-fourth the average length of the fascines.

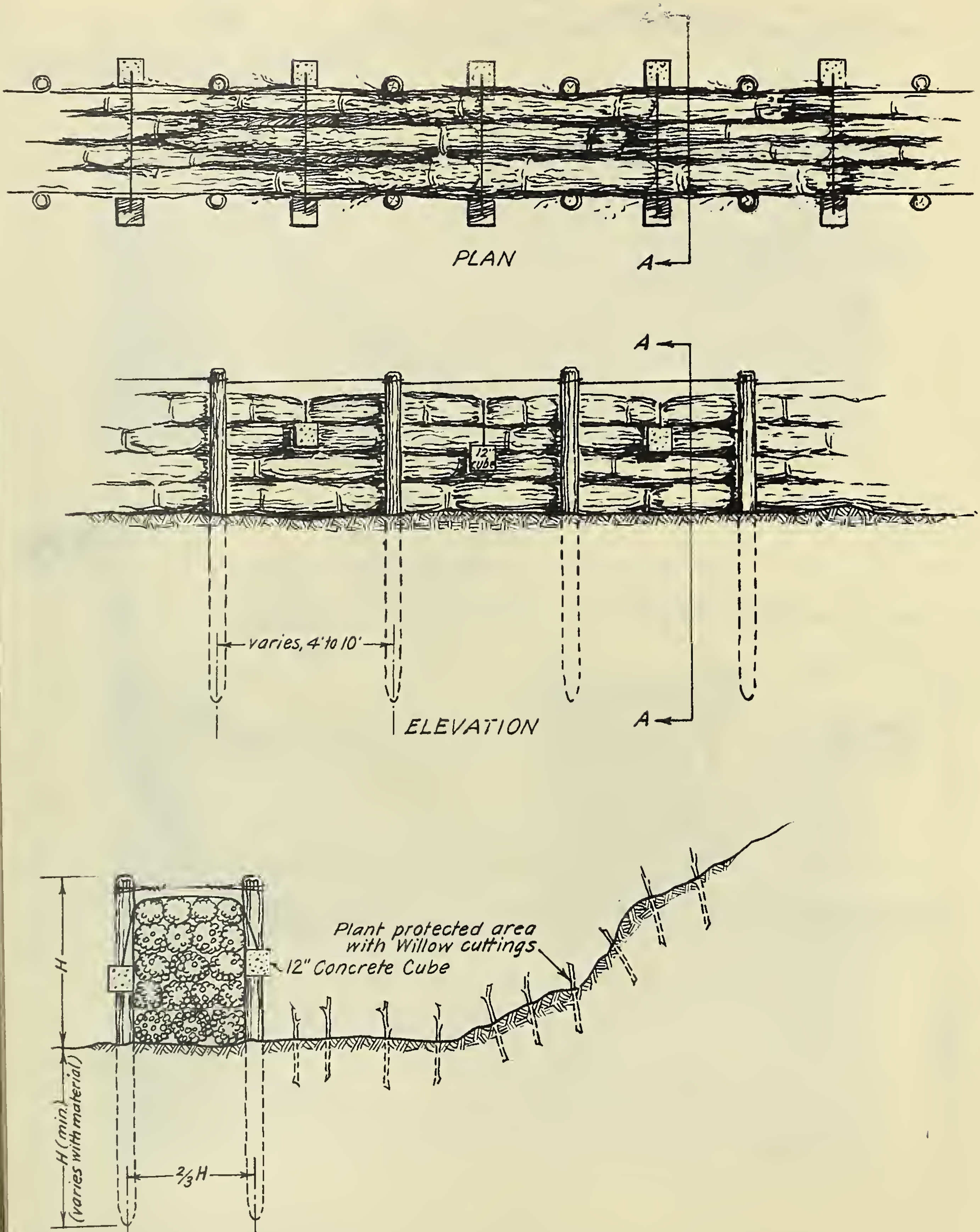


FIGURE 18.

PILE AND FASCINE DIKE CONSTRUCTION

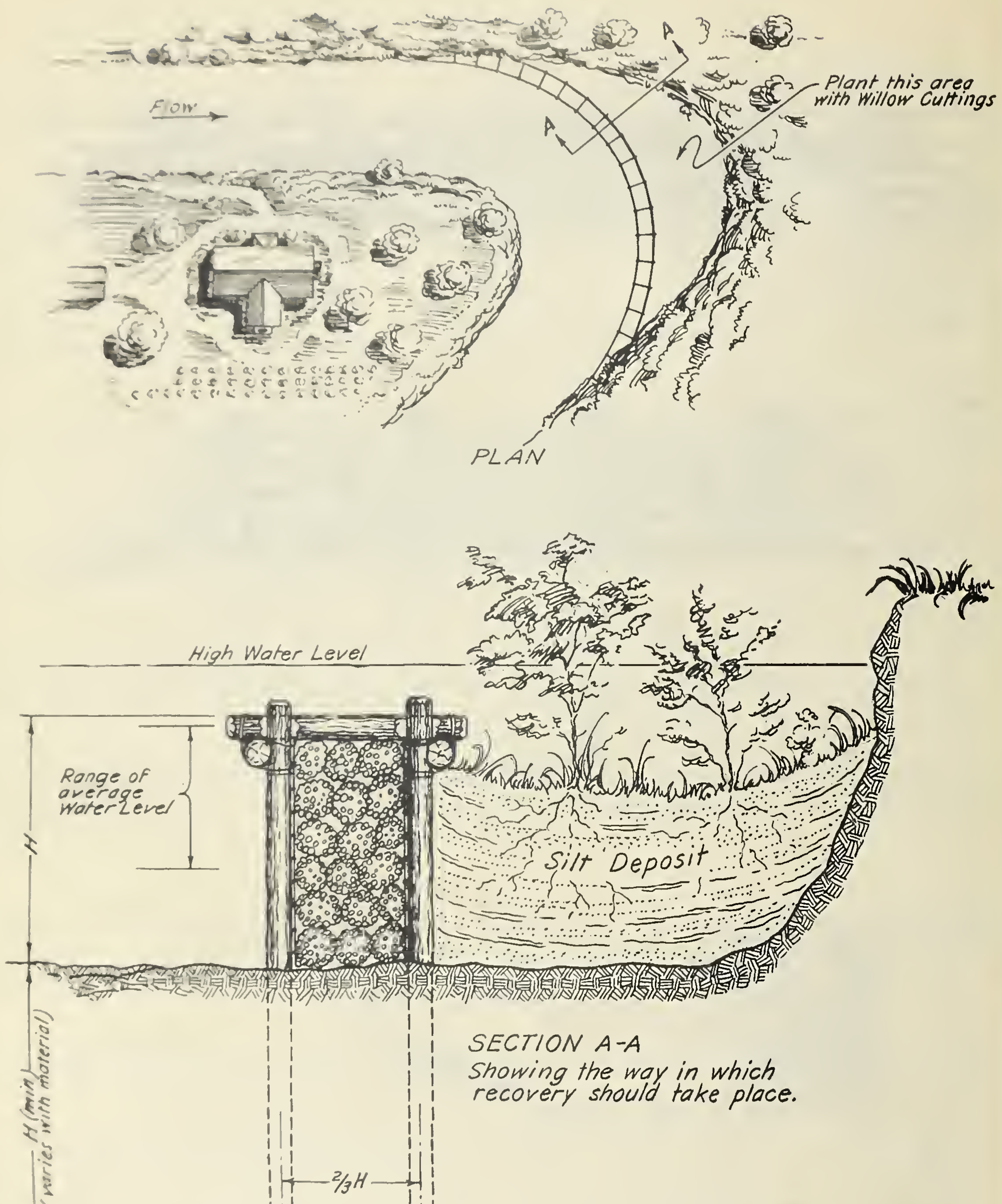


FIGURE 18-a
CONTINUOUS DIKE PROTECTION
ON CONCAVE BEND

Figure 18b

Rock and wire mesh jetty along the Virgin River, Utah, showing well advanced recovery on the protected side. (R-4).

Figure 18c

Close view of rock and wire mesh jetty along the Virgin River. (R-4).

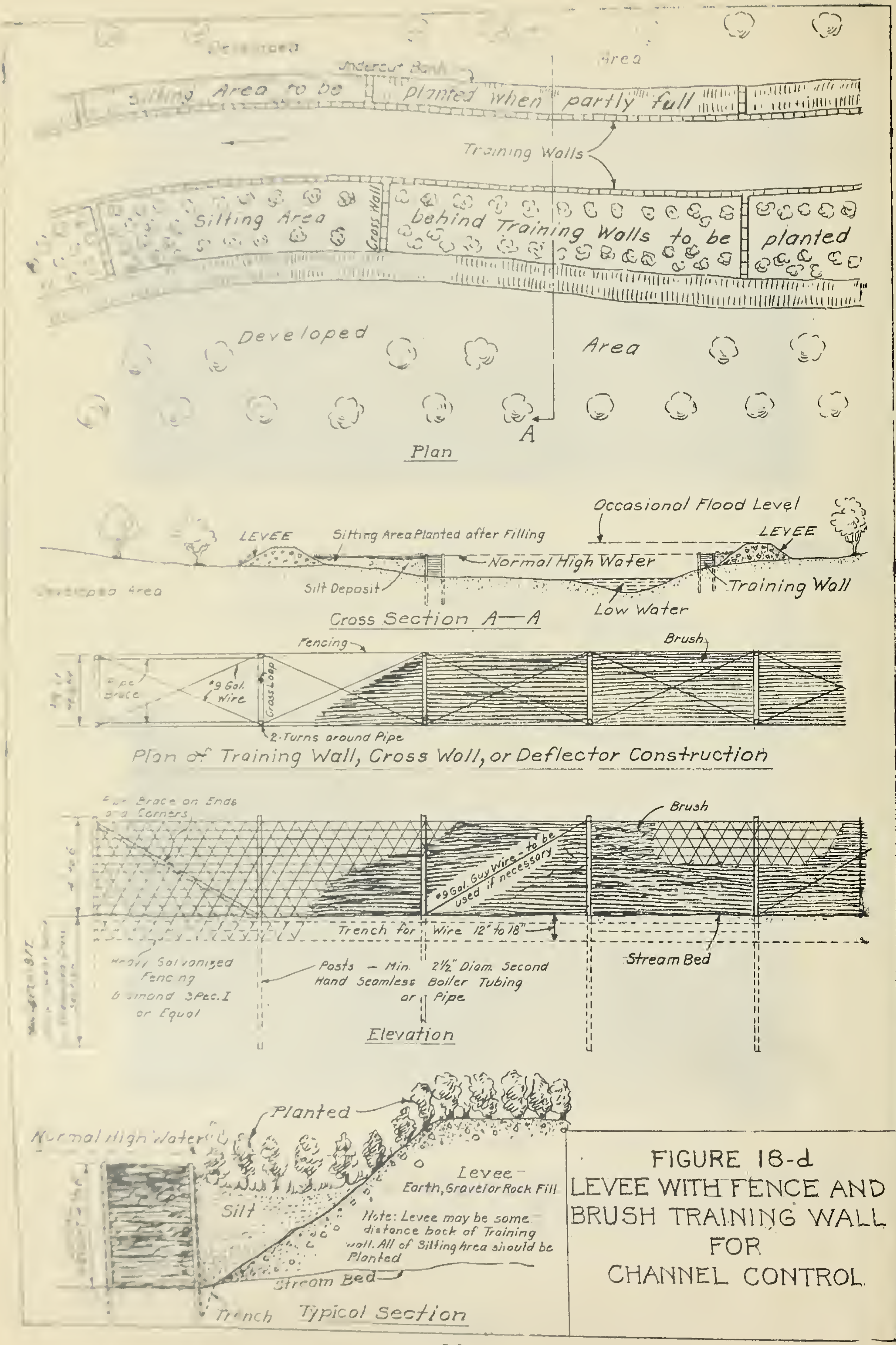


FIGURE 18-d
LEVEE WITH FENCE AND BRUSH TRAINING WALL FOR CHANNEL CONTROL

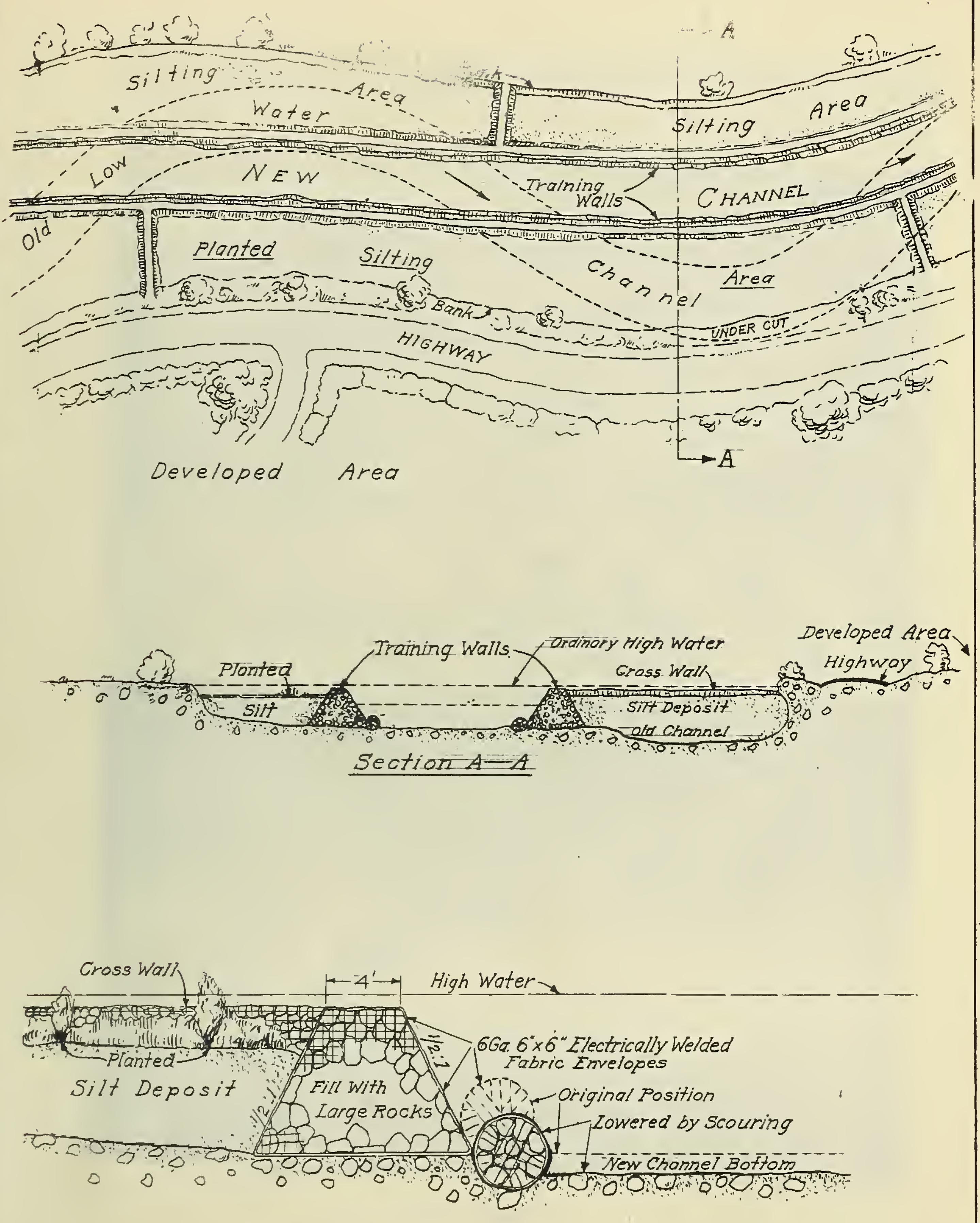


FIGURE 18-e
ROCK TRAINING WALLS
FOR
CHANNEL CONTROL

Figure 18f

Failure of rock and wire jetty where the flow was too swift and turbulent, resulting in greater damage.

Figure 18g

Another failure due to high velocity flow.

Figure 19

Fill slope on the San Gabriel Road, Angeles National Forest, California. Protected by brush wattles constructed by the California Forest Experiment Station.

The fascines are held in place with weighted cables which are slung across the top in each bay, as illustrated in Figure 18. The slings are made with 1/4 inch galvanized cable, having each end broomed out and embedded in a cubic foot block of concrete. After a few months use, it is usually necessary to remove the ballast cables and build up the brush fill to take care of settlement.

The penetration of the piles will depend on local conditions, but should be sufficient to provide security even after a large amount of erosion has taken place. The size and species of pile used will depend upon local factors. Since the tops of the piles will be subject to conditions which are favorable to decay, the use of species with good decay resistance qualities is of primary importance.

3. Continuous dikes. In some cases, rivers have cut into their banks extensively and have wide channels far in excess of the need as far as water capacity is concerned. The normel and low water flow courses back and forth across the channel, cutting further into the banks at various places. Under such conditions, restriction of the major stream to a limited central portion of the channel is feasible, for which purpose continuous longitudinal dikes are the obvious choice. They are usually supplemented by cross dikes to the river's banks at intervals to retard water velocities and aid in silt deposits. The same type of structure which is used for spur dikes meets the requirements for continuous dikes. Figure 18a shows the essentials of an installation of this kind, Figure 18b is a photograph of an installation on the Virgin River near Mt. Carmel, Utah, which has met with considerable success. A side view of one of these dikes, of rock and wire mesh construction, is shown in Figure 18c.

Another use for continuous dike protection occurs in relatively narrow, fast flowing rivers, where it is not feasible to cut back the bank for slope paving, as along valuable agricultural land, highways, and so forth. The toe of the caving bank can be protected by a continuous dike as in Figure 18a. As a rule this type of dike is subject to greater cutting action along its outer face, and should therefore be founded well below the depth of possible erosion.

Figures 18d and 18e show other variations of jetty construction, using different materials. It must be borne in mind that the useful life of any type is dependent upon the life of the material of which it is made.

The photographs shown in Figures 18f and 18g illustrate the result of construction of a wire basket and rock jetty where conditions were not at all suited to it. The jetty obstructed a large percentage of the water area and so forced an increase in the velocity, which was already so high that it was eroding the gully. The increased velocity also increased the transporting force of the water and so aggravated a condition already bad. The remedy for the restoration of the gully shown in these two photographs is not to be found in the channel control methods of this Section, but rather in the use of gully control devices described in Chapter IV.

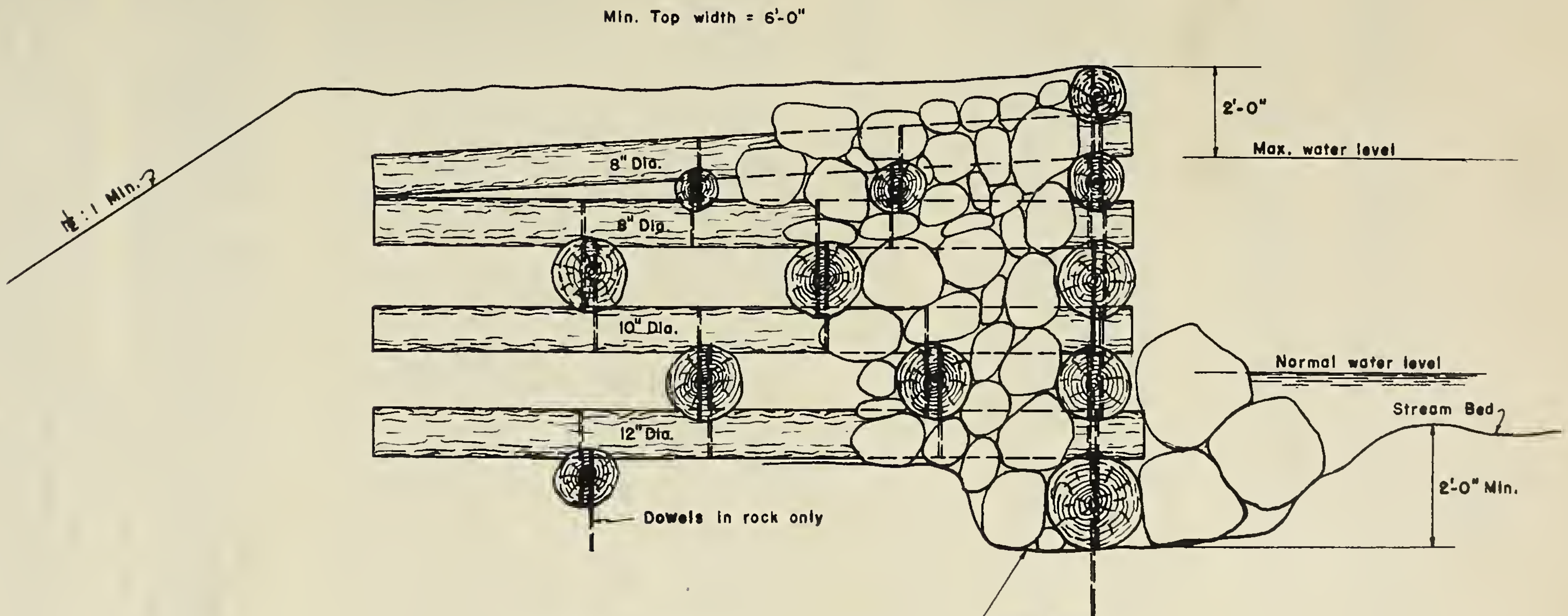
14. Road Fills and Cuts.

Road-bank protection is not within the scope of this handbook. Detailed information on the subject will be included in the Truck Trail Handbook.

Both the Appalachian Forest and Range Experiment Station and the California Forest and Range Experiment Station have done a large amount of research on road-bank protection and they should be consulted on such work to obtain the latest developments in vegetative control.

Figure 19 shows a fill slope on the San Gabriel Road, Angeles National Forest, California, which has been protected by means of measure i - brush wattles, which held the loose soil in place and allowed the green stakes driven into the wattles and the wattles themselves to sprout and grow. Note in this picture that a good growth of vegetation has begun. These measures are particularly effective on high fill slopes where there is danger of sliding and where the rainfall is light.

Measures g, planting, and h, mulching, are also effective for road-bank protection where there is sufficient rainfall to give the vegetation a quick start. In the Appalachian Mountains good results have been had by planting honesuckle and other quick-growing vines. They are usually planted in pockets which have been dug out of the cut bank and filled with top soil.



TYPICAL SECTION OF CRIB

Scale 2'-0" = 1"

Typical Rock-fill Timber Crib Dike

Rock-fill, timber crib dike to protect Campton Forest Camp, White Mountain National Forest, from Mad River.

Bottom logs are four feet below river bed, and top logs three feet above known high water.

Small stones between logs and large "derrick" stones along front of dike taken from river channel.

Logs are peeled and tied together with 1-inch iron pins. Enduring species of wood were selected. Native materials permit low cost.

Typical Crib Deflector

The river discharge approaches this deflector [illegible] angle of about 45 degrees, and is directed toward a stone cli[illegible] protecting the flat Camp area behind the crib. An auxilli[illegible]llels the channel below the deflector. Deflector angle[illegible]l conditions - are usually less abrupt than this.

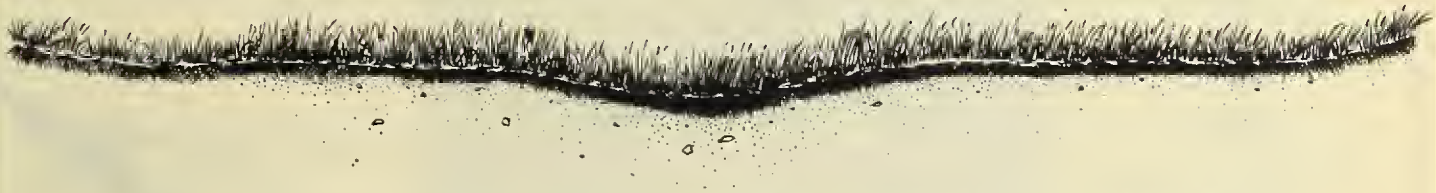
The upstream end of the crib is deeply anch[illegible]ded with cut off to prevent erosion behind [illegible] cribbing.

The crib section is designed with allowance [illegible] so that it can be over topped without damage.

Close up of Rock-fill Cribbing Construction

Note fitted, staggered joints which are pinned with 1-inch iron dowels.

Small deflector just upstream from bank-protection crib dike to prevent erosion behind dike. Small amount of leakage through this structure is expected and desirable. Where deflectors or jetties are of sufficient importance and size, model tests are justified.



Trough of valley in natural state. Protected by heavy sod.

Gully formed in trough of valley by increase in rate of runoff and decline of sod cover.

Second-stage causing depletion of vegetable cover in valley and lowering of water table. Sage brush is replacing grass.

Overfall-Gully depth "A" increases to depth "B"

FIGURE 13

CROSS SECTIONS SHOWING THE SUCCESSIVE STAGES IN THE FORMATION OF A GULLY

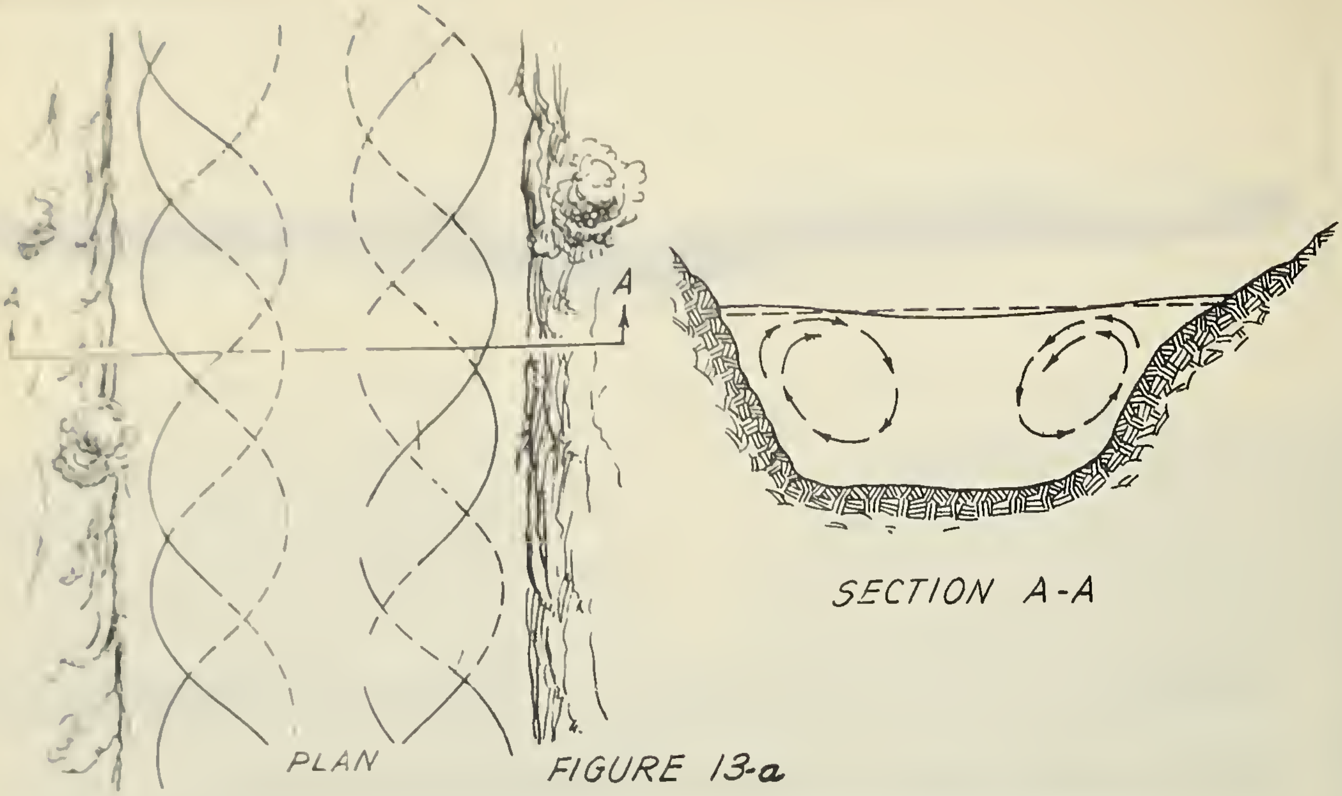


FIGURE 13-a
TRANSVERSE CURRENTS IN A STRAIGHT CHANNEL
OF UNIFORM CROSS SECTION

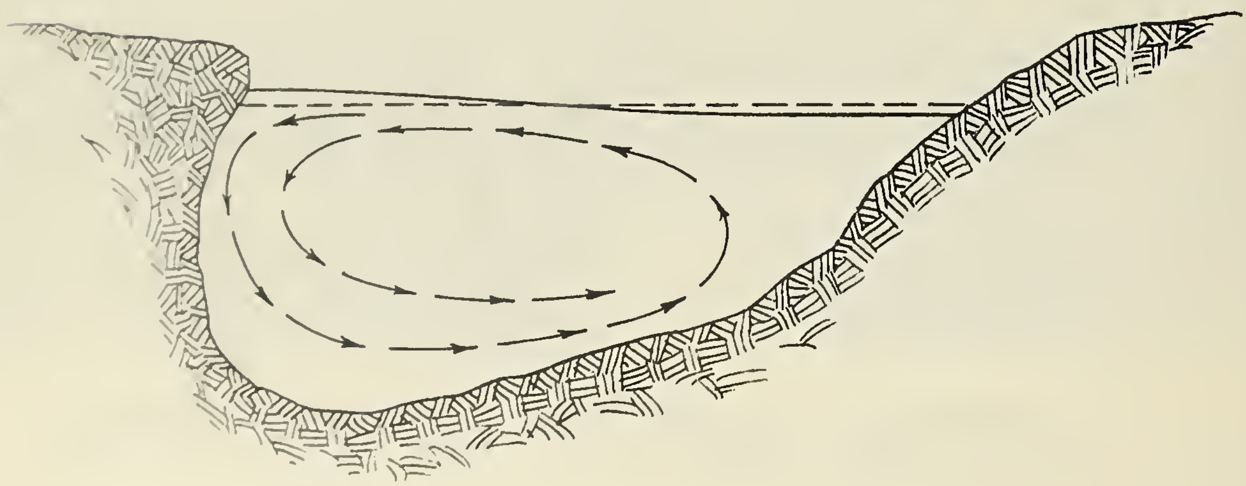


FIGURE 13-b
TYPICAL CROSS SECTION
SHOWING SPIRAL CURRENT MOVEMENT AT RIVER BEND

FIGURE 14.

DEBRIS BASIN NEAR SALT LAKE CITY, UTAH—CONSTRUCTED BY UNITED STATES FOREST SERVICE.

l as described under Section 6. There are two general methods of accomplishing this result. One is to construction the dams of permanent material to the full height that it is desired to raise the gully. The other method is to construct a series of low temporary dams and later construct other similar dams on the silt deposits, continuing this process from year to year until the gully is filled to the desired height.

The possibility of continuance of funds for several years will determine whether the second of these methods can be adopted. It will usually be the cheaper of the two.

12. Mud and Debris Flows.

Due to denuded areas on some watersheds, heavy seasonal rains cause large quantities of eroded material to flow from the steep canyons and spread over the flood cones at their mouths. Because these floods of debris often cover valuable land, railroads, and highways, it is necessary to construct works to control them and check their spread until such time as the vegetation on the watershed becomes dense enough to prevent their recurrence. See figure 7.

Figure 14 shows a typical debris-basin development at the mouth of a small canyon near Salt Lake City, Utah. The component parts of this work are indicated by letters on the picture as follows:

- A, the earth dike.
- B, the masonry spillway.
- C, spreading structures within the basin to cause the flood to spread and deposit part of its load at the upper end of the basin.
- D, masonry openings through dike for irrigation ditches. These are provided with gates which can be raised as the debris deposit raises behind the dike.

The earth dike A was simply pushed up to a height of 10 feet by tractors equipped with bulldozers. No attempt was made to roll, dampen or otherwise compact the dike as it will ordinarily not be required to hold any appreciable amount of water. The floods coming behind it will consist largely of earth and rock with just enough water to make it flow.

The masonry spillway is designed on the same principle as any masonry dam. See section 37 for details on masonry spillway construction.

The spreeding structures are constructed of masonry in a V-shape with the points upstream. The points of the structures are cemented while the wings are of dry masonry. See section 41 for further details.

The openings for irrigation ditches are placed where existing ditches were located. They have a gate which can be closed to prevent floodwaters from getting into the ditch. The gates are constructed so they can be raised as the debris level rises inside of the dike.

13. Channel Control.

A. The Peculiarities of Stream Flow:

Gravity is the motivating force behind the flow of water, causing it to pass from high to lower elevations, or to use the common expression, to flow down hill. When the water surface drops to a lower elevation, the energy equivalent to the drop in elevation, or head, is converted to velocity. The fixed relation between head and the velocity which it will produce is represented by the equation $v = \sqrt{2gh}$, where v is the average velocity in feet per sedond, g is the acceleration of gravity (32.2) and h is

the loss of head in feet. Conversely, $h = \frac{v^2}{2g}$, $\underline{h}$ representing the head which will produce a certain velocity, $\underline{v}$. Therefore, any known velocity $\underline{v}$, can be converted back to the head, $\underline{h}$, which caused that velocity, in which case $\underline{h}$ is known as the velocity-head for that particular condition. Another force to be considered is that of friction, for there is a certain amount of energy lost in overcoming the friction of water against the sides of the channel and within itself, as described later. At any point in the channel, the drop in head from the initial point is equal to the increase in velocity head plus the head lost in friction in the interval.

It is of particular importance in river hydraulics to recognize the fact that water does not move forward in uniform, parallel layers, but instead is subject to regular pulsations, combined with very irregular eddy and roller motions. The cross-sectional area and the velocity change continually, but mathematically every change in velocity must correspond to a change in surface elevation. In any particular reach in which the cross-section has a trough or U-shaped form, the water flows more rapidly in the middle and at the surface, and more slowly at the shores and along the bottom. Due to the friction of the fast moving particles in the middle against the slower moving particles on the outside, the flow is attracted from the shores toward the center and continually moves from the zone of slow edge velocities to the zone of more rapid center velocities. Because of this motion, it is evident that a transverse gradient exists, and the water surface at the middle of a river must be lower than at the edges of straight reaches.

This condition holds not only when the quantity of flow of water is constant, but also when the stage is falling. The condition is reversed for a rising stage. The only significance this has to our problem is to emphasize the fact that in river flow there is no such thing as parallel or laminar flow, and that even straight reaches of river channel are subject to the erosive action of transverse currents, as shown in Figure 13a.

If, as is frequently the case, the material on one bank is more erosible than the other, the once uniform section is cut away at that bank, introducing a bend in the channel which results in a spiral motion of the water. The transverse movement becomes increasingly greater, and the inertia of the moving water around the bend raises the water surface on the outer or concave side of the bend, thus further aggravating the spiral motion. The superelevation of the water influences the velocity and direction of flow around the curve, and it follows that water must flow continually from top to bottom at the concave shore, as illustrated in Figure 13b. It is evident that after a bend has once started, there is a constant tendency for the curvature to become greater.

The control of streams which are subject to large periodic flood flows and which have unstable erosible soil for their bed and banks is further complicated by the presence of a variable amount of solid matter that is carried by the water. This solid matter may be divided into two types,

1. Suspended matter, which travels great distances suspended in the flowing water, and which settles only when the velocity decreases, or when the distribution of velocity changes.
2. Detritus, or bed load, which moves by sliding, rolling, and jumping along the bottom of the channel, and which may also travel great distances.

Their laws of occurence are similar, and it is not usually possible to distinguish one from the other after the two types have been deposited. However, the source of the detritus is more often the upper part of the stream, where it comes from the weathering and erosion of the mountain slopes, and generally contains the coarser and more abrasive particles. The finer particles that go into suspension are more often acquired from the lower reaches. It is the presence of this solid matter that makes it possible to so direct and control the stream currents as to build up protecting bars and deposits which prevent further damage to the banks.

The amount of solid matter carried by a stream varies according to the stage. The higher the flood stage the greater will be the velocity and the transporting power of the water. A measure of the transporting force of streams in which the width is more than 30 times the depth may be computed from the formula:

$$F = 62.5\ d\ s \qquad (1)$$

in which $\underline{F}$ is the transporting force in pounds per sq. ft. $\underline{d}$ is the depth of the water, in feet, and $\underline{s}$ is the slope of the water surface expressed as the ratio of vertical drop to horizontal distance.

For narrower streams a more exact determination of the transporting force may be made by using the hydraulic radius of the section in place of the depth in formula (1).

Table I gives the transporting force, called the limiting force, required to start movement of various kinds and sizes of detritus. The transporting force at which moving sediment begins to settle is about 70% of the limiting force at which it begins to move.

Table I
Limiting Transporting Force of Detritus

Kind of Detritus	Size of grains	Screen Size or diameter	Transporting Force in lbs. / sq. feet
Clayey Soil		passing #40	0.2 to 0.25
Sand	0.20 to 0.40 mm.	#75 to #40	0.04
"	0.40 to 1.00 mm.	#40 to #18	0.05 to 0.06
"	graded up to 2.00 mm.	Passing #10	0.08
Gravel	0.5 to 1.5 cm.	#4 to 9/16"	0.26
Coarse gravel	4.0 to 5.0 cm.	1-1/2" to 2"	1.0
Flat limestone chips	1 to 2 cm. thick,)	3/8" t 3/4"	1.15
	4 to 6 cm. long)	1-1/2" to 2-1/4"	

Another factor, the amount of which cannot be measured, has much influence on the transporting ability of flowing water. This factor is the turbulence, for upward currents which accompany it tend to keep soil particles in the suspended state. Clear water is more erosive than turbid water because it can gather new particles to transport, whereas turbid water has already acquired its load of detritus.

Structures for the control of river currents should not be built until after an analysis has been made of the hydraulic reasons for the particular fault which must be corrected, and of the hydraulic action which will take place after the structures are in place. It must be borne in mind that regardless of the structures built, there will be no reduction in the quantity of water to be passed, and that there is a direct relation between the quantity of water, its cross-sectional area, and its average velocity. Any obstruction which reduces the area will be unavoidably followed by a proportionate increase in the average velocity, which may so increase the transporting force as to start troublesome erosion at previously stable points in the stream.

B. Protection Methods.

The most efficient method of channel bank protection is one which guides rather than opposes the course of the river, and results in the formation of accretions in front of the caving banks and other vulnerable spots. If the river currents can be induced to do the work by structures made from materials provided by nature, the cost need not be great. The problem is reduced to the choice of the type of structure, its proper location, construction and maintenance. Obstructions placed in the bed of a river to

build up bars as a protection against erosion are useful in slow-moving, heavily silted streams where the structures will not cause a detrimental increase in the water velocity. Their usual effect in swift streams is to cause erosion of the bank opposite the structure because of increased current velocities, or to increase scour on the channel bottom, which will ultimately undermine and destroy the obstruction.

If the damage is being done on straight reaches of the river it will ordinarily be necessary to protect both banks, the layout of the structures being guided by the location of the troublesome spots. Protection will be needed only on the concave side of curves. The toe of the bank will be subject to the most severe cutting action and must therefore have better protection than the higher parts of the bank.

Three general types of channel protection are:

1. Slope protection.
2. Spur dikes.
3. Continuous dikes.

1. Slope protection. Riprap is the simplest kind of slope protection to build. It consists of quarry stone placed on the slope from top to bottom, to withstand the erosive action of the water and is most commonly used for road or railroad fill slopes adjacent to streams where the water velocities are not excessive. The slope of the embankment under the riprap must be flat enough to be stable when saturated with water. The purpose of the rock riprap is to give the additional protection needed to withstand the current.

The rock is usually dumped from cars or trucks at the top of the bank. The structure is built up from the bottom, where the deposit will be the thickest and the most useful because the toe of the embankment is where the greatest protection is needed. However, ordinary riprapping is effective only for velocities of moderate severity in straight or moderately curving channels. Riprap made of large pieces of rock placed individually by derrick may resist very strong currents, as shown in Table II.

Table II
Allowable Tractive Force of Protection Elements

Kind of Protection	Tractive Force
Sod revetment (short periods of attach)	0.4 lbs. / sq. ft.
Fascine Paving	1.4
Well laid stone paving 1 ft. thick	3.3
Random riprap (stones 100 to 1000 lbs.)	5.1
Rock or fascine filled crib or piles	12.3
Rockfilled timber cribs on rock foundation	30.0

Tractive forces greater than 30 lbs. per sq. ft. can be withstood permanently only by heavy, well founded concrete or massive masonry structures.

Where sufficient rock is not available for riprap, a mat of brush, bound with wire and weighted with rocks or other ballast, may be used. Adequate protection against undercutting at the toe of the slope is essential. Figure 15 shows details of one type of brush paving known as the fascine mattress. For extreme conditions, concrete or other more permanent massive masonry structures are required, but they will be relatively expensive.

The fascine mat is woven from bundles of willows or other brush which grows in abundance along many rivers. The individual saplings should be at least 14 feet long,

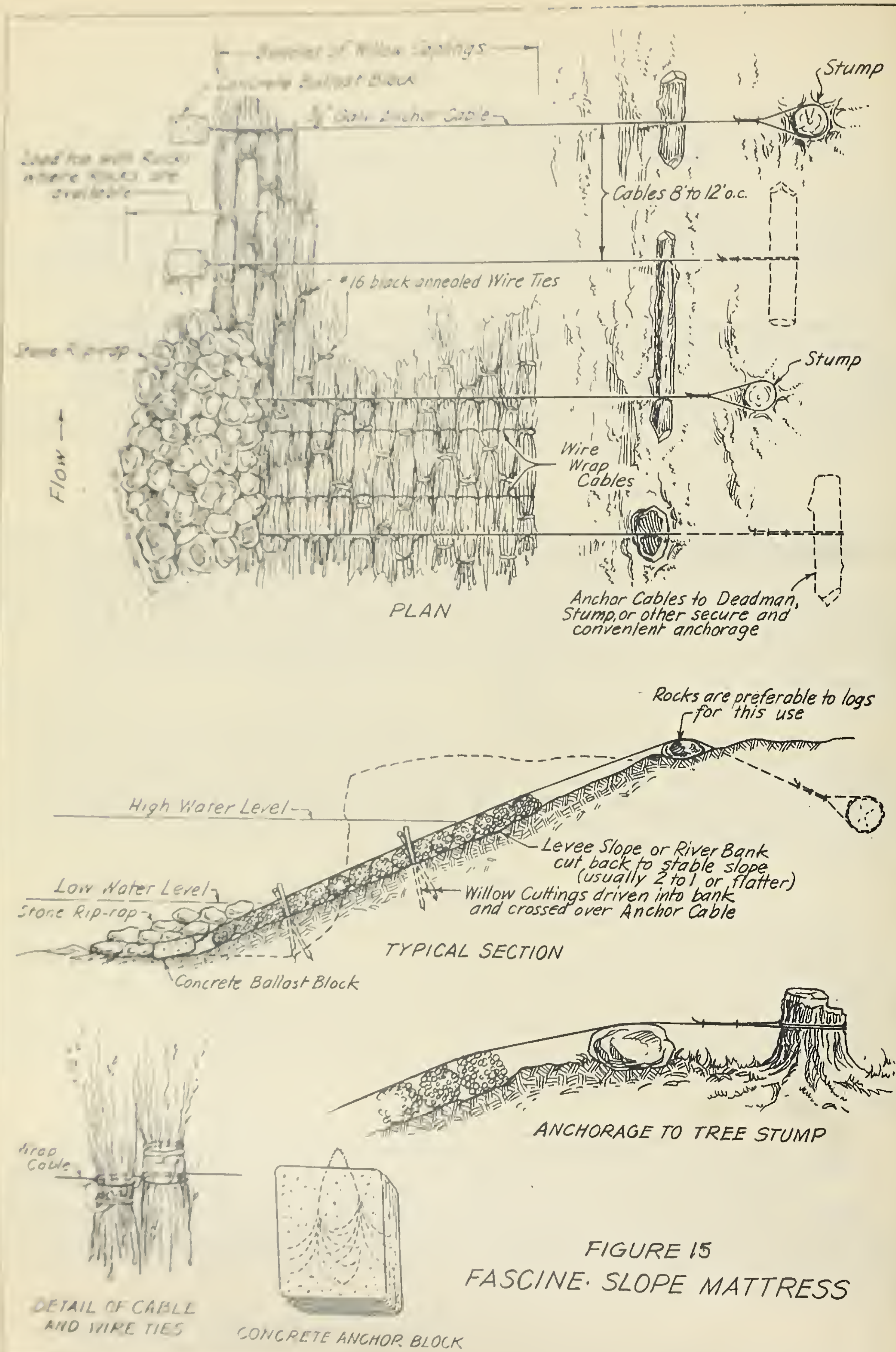


FIGURE 15
FASCINE SLOPE MATTRESS

and longer if possible. They are bound into bundles about 12 inchee in diameter at the butt, ueing black annealed wire not smaller than No. 16 gauge. There should be not lees than three bands of wire, uniformly spaced at 3-foot intervals, beginning one foot from the butt end of the bundles.

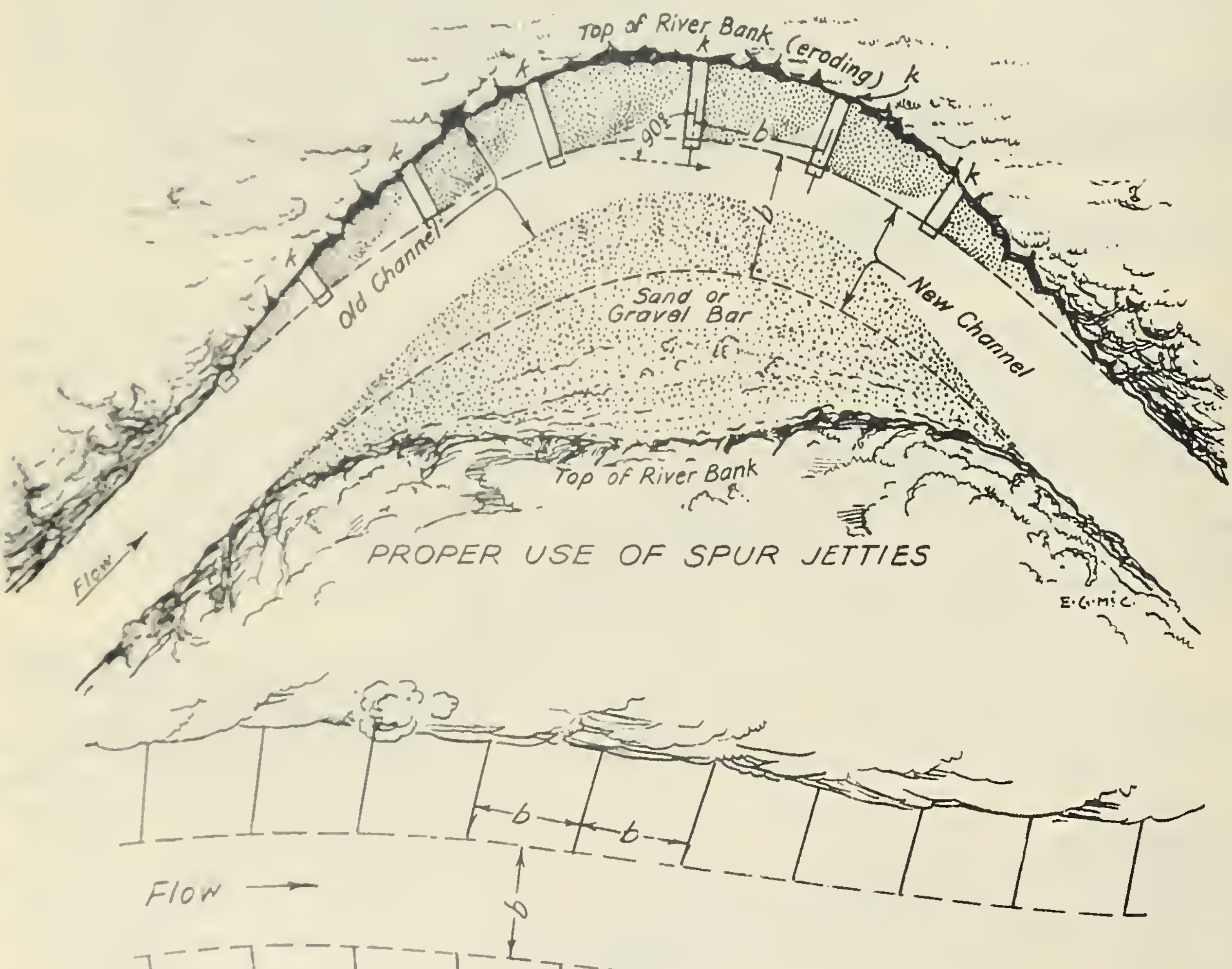
The mattress is built, either floating over the final position, or supported on a barge with eloping ways on the shoreward eide. Fascines, with butts upstream and overlapping the tips about two feet, are placed side by side, and bound closely together with flexible galvanized wire cable, usually one-fourth inch in diameter for emall projects. Each loop of the cable is held in place with a tie of No. 12 wire. For large mats, or in ewift currents, additional rigidity can be secured by weaving poles in with the cablee, at right angles with the fascines. When fabricated, the mat is sunk to the bottom by loading it with rock, or with a concrete block ballast and anchor cable arrangement as shown in Figure 15. At least 14 pounds of ballast per square foot of mattrese will be required. Anchor cables may be eecured to dead men, stumps, or other available anchorage along the bank, the epacing depending upon the anchorage available. The spacing should not exceed 12 feet, and each concrete ballast block muet be heavy enough to hold down the intervening mattreee area.

Liberal use ehould be made of stakes and wattles of willow cuttings in all the foregoing schemes, as growing willowe will add greatly to the effectivenese of all of them.

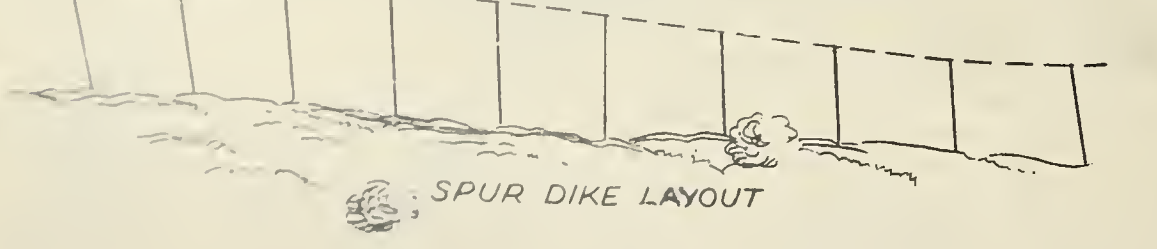
2. Spur dikee. Dikee or jetties are built to divert the current away from vulnerable areas so that silt and eand bars will be created on the sheltered side of the structures. The location of the jettiee and the methods of construction are of equal importance. It is aleo essential that the dikes and the bars behind them be planted to willows or similar growth to make the etabilization permanent. In planning this type of protection it muet be remembered that the jetty, although not water tight, obetructs the channel becauee it reduces the effective area and is the cause of increaeed velocity in the unobstructed part of the channel. In some cases it causes vital changee in the direction of flow. Both increased velocity and change of direction of the current may become new sourcee of trouble at other points along the stream.

Consider the example of a channel with a sharp bend and which flowe bank full during normal and flood stages. If both banks are composed of erosible material, it will eeldom be advieeable to build epur jetties to protect the concave side, because they will occupy too much of the cross-section area, and will direct the current to the convex side where the erosion may be continued. Slope paving or continuous dikes would be more suitable for this condition. However, there are many cases where the concave bank has been eroded so far back that there is excess width between banks. In thie case, spur jetties will cause a readjustment of the flow within the original banks and will be the most effective corrective measure available. Figure 16 illustratee thie point. The upper diagram shows the unfavorable condition, and the center diagram shows the favorable condition. In the upper diagram, the arrows at E point to the area in which the concave bank has been cutting away. The bank at F ie as high as the other eide, but hae been etabilized by vegetation, without help, because the force of the current ie directed away from it. However, if the channel is obstructed by jetties on the concave side, the current will be directed toward area F with greater force and the trouble at E may be transferred to area F where considerable damage may be done. The center diagram illuetrates the condition in which the loss on the concave side, K, has continued for so long that there is a wide expanse between the banks, part of which is occupied by a gravel bar that is flooded during high water periods. In this case spur jetties will cause a shift from the old channel to some such position as that marked "new channel", and will hold it ae long as the concave bank protection stays effective.

IMPROPER USE OF SPUR JETTIES

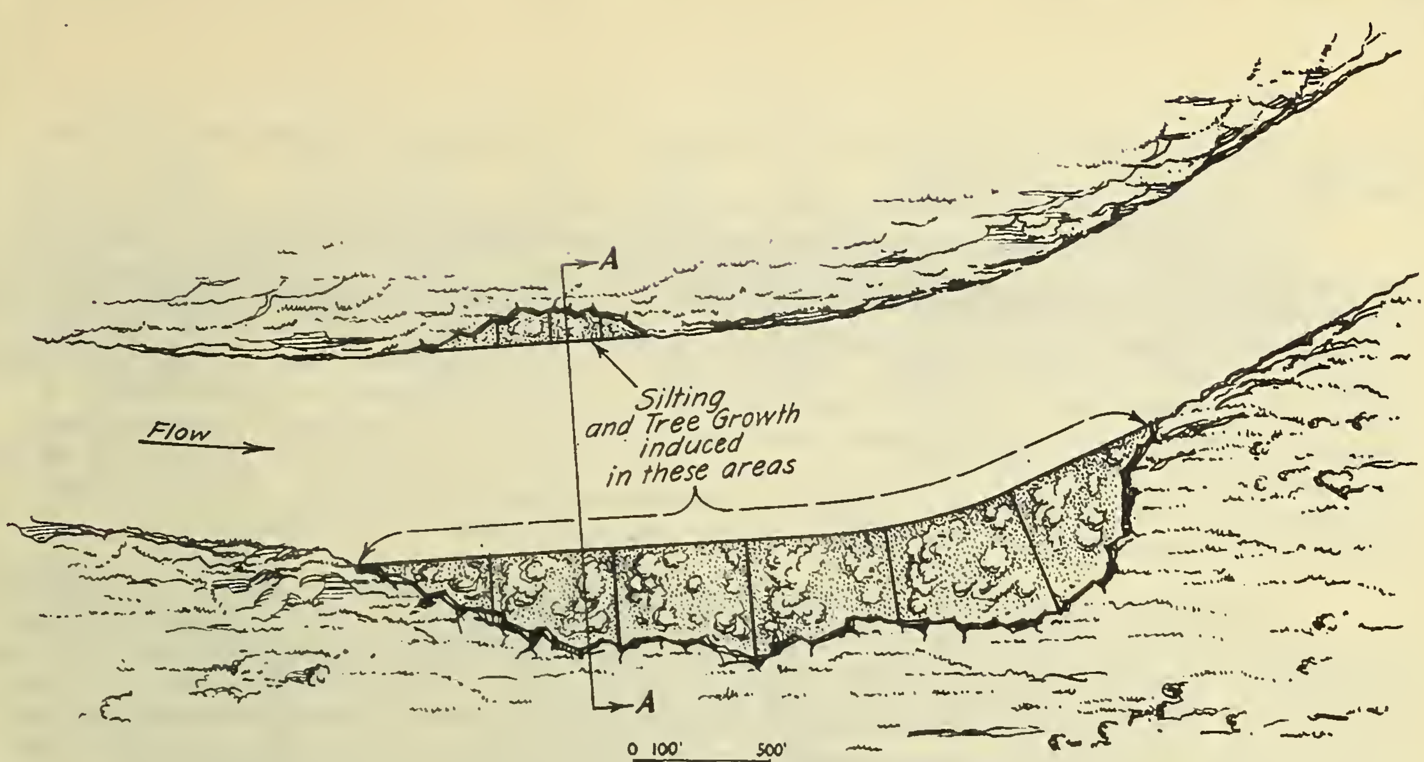


PROPER USE OF SPUR JETTIES

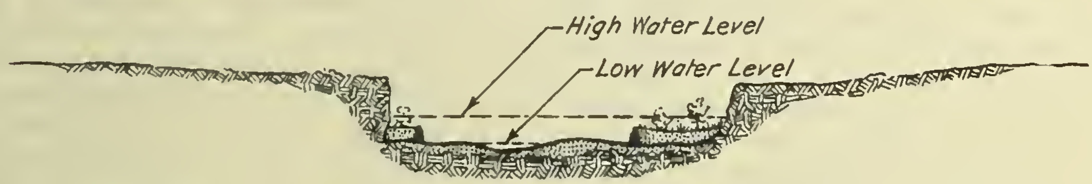


SPUR DIKE LAYOUT

FIGURE 16
USE OF SPUR JETTIES

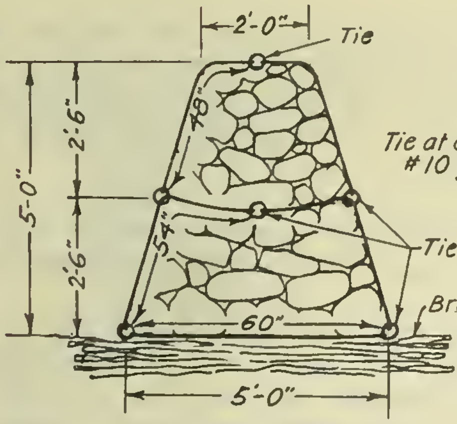


PLAN

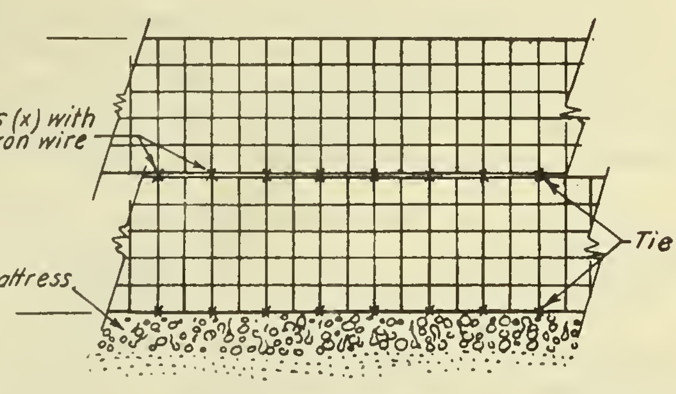


Streambed composed of shifting bars of silt and fine sand

SECTION A–A
(Vertical Scale exaggerated)



SECTION



SIDE ELEVATION

WIRE BOUND ROCK JETTY

Wire envelope to be 6 ga. 6"×6" electric welded fence wire, using 48", 54", and 60" widths as required. For dikes of different heights, use proportionate dimensions with whatever widths of wire are required.

In completing the bottom section, the rock fill surface should be 3" lower in the middle than at the edges, and the wire drawn tightly together. When rock for the top section is added, the sag takes up the remaining slack in the bottom wire, giving a tighter finished job.

FIGURE 17

GENERAL PLAN OF
CHANNEL CONTROL SYSTEM
FOR LOW VELOCITY RIVERS
WITH SHIFTING SILT BOTTOM

liberal use of shrubs and trees which will build up strong root systems are vital to any enduring protection scheme.

There is no fixed rule which determines the spacing between the individual spurs, or the angle which they make with the direction of the current. The factors depend on the combination of conditions at each location. In general, on concave curves, the spur should be at right angles to the thread of the stream, as shown in the lower diagram of Figure 16. This tends to prevent longitudinal currents along the face of the spur, and water which flows over the top of the spur is not directed toward the river bank. A spacing between spurs approximately equal to the width of the confined river channel will usually be sufficiently close to cause the desired silting action as rapidly as is necessary. Closer spacing will tend to increase the rate of deposit, but is seldom justifiable because of the increased cost of the additional structures.

It has been found that the rate of sedimentation on channels where the curvature is slight has been more rapid when the spurs are turned so that the shore end is somewhat downstream from the outer end. The advantages of this alignment are that the current action along the spur face is less severe, and the direction of the overflow current during high water is away from the stream bank. However, the undercutting action at the head of the spur is more severe, and therefore more protection against this action is required. For all conditions, it is important that the foundations of the jetties be carried down below possible scour level.

A cross section of a rock and wire basket jetty is shown in Figure 17. The base is laid on a mat of loose brush, which should have a compacted thickness of about eight inches and project from nine to twelve inches at each side. Details of wrapping the wire are shown in Figure 17. No attempt should be made to make the jetty impervious, because it is not built to withstand water pressure and the water depth should be the same on both sides. The value of the jetty lies in the fact that it retards the water velocity to the point where much of the suspended silt is deposited, building up bars where trees and brush can be induced to grow, either naturally or through planting. The stimulation of brush and tree growth should be the object of all of this protective work, so that after the structures have rotted away or otherwise failed, the corrective work will still endure.

Wire bound dikes should not be used along rivers which carry a bed load of sand, gravel, or rock during flood flows. The abrasive action of these materials on the wire soon wears it through and the loose rock fill spills into the river, causing failure of the dike. If the bed load contains more than 20 percent of sharp stones retained on the #10 screen the abrasive action will be harmful.

For general use, the timber pile and fascine jetty type of construction will be found very satisfactory. If cutting occurs along the face, the jetties are protected against failure by the penetration of the piles.

The piles are driven in double rows with a space of 3 feet or more between rows, and tied together at the top with cable. The cable is secured to the pile top with heavy staples. The cable should be 3/8 inch diameter (galvanized) for small dikes, increasing to 1/2 inch for more severe usage. The space between the two rows of piles is filled with willow fascines, the relation between the pile spacing and the fascine length being such that each bundle will be retained by at least three piles. The longitudinal pile spacing should not be more than one-fourth the average length of the fascines.

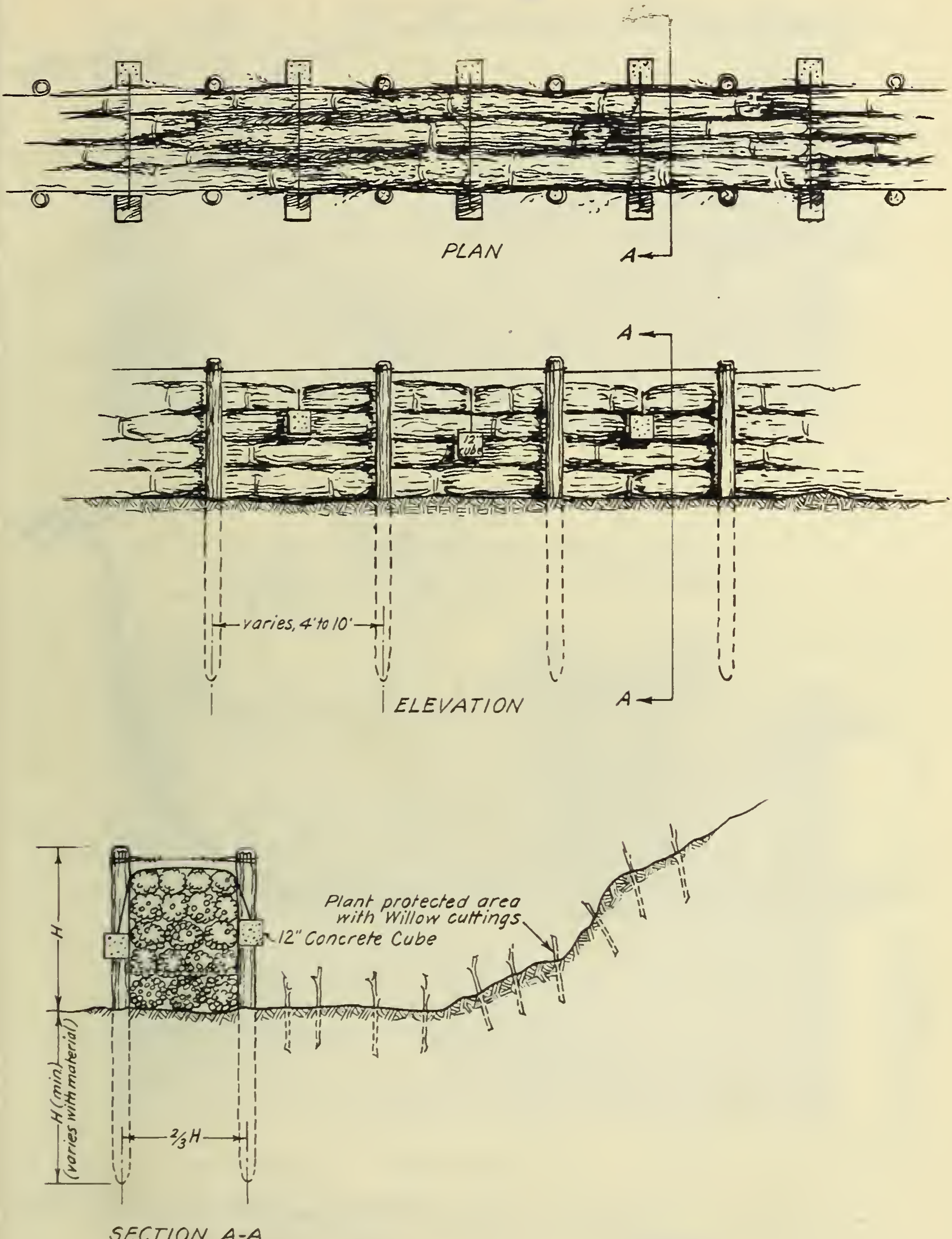


FIGURE 18

PILE AND FASCINE DIKE CONSTRUCTION

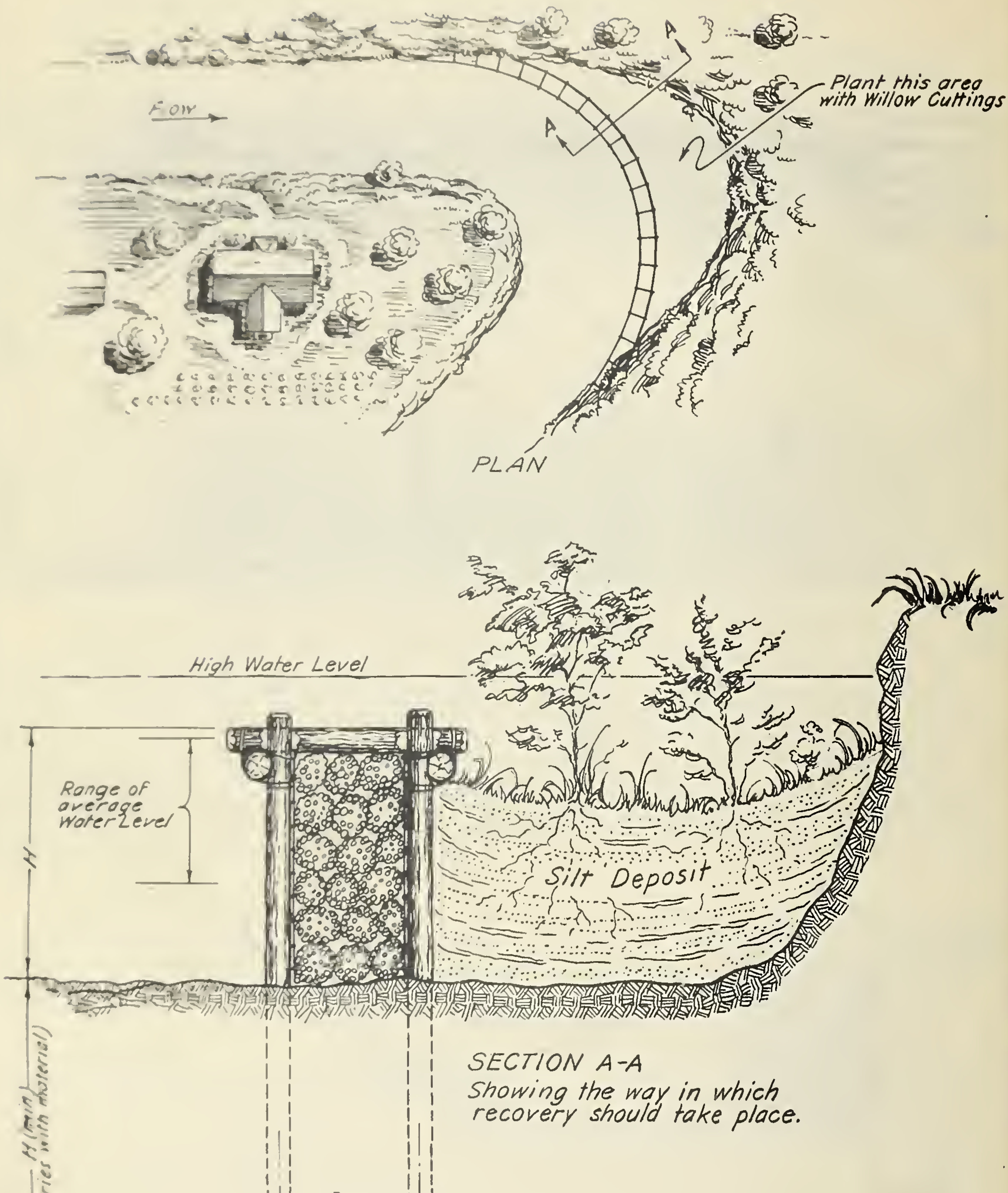


FIGURE 18-a

CONTINUOUS DIKE PROTECTION ON CONCAVE BEND

Figure 18b

Rock and wire mesh jetty along the Vir-
gin River, Utah, showing well advanced
recovery on the protected side. (R-4).

Figure 18c

Close view of rock and wire mesh
jetty along the Virgin River. (R-4).

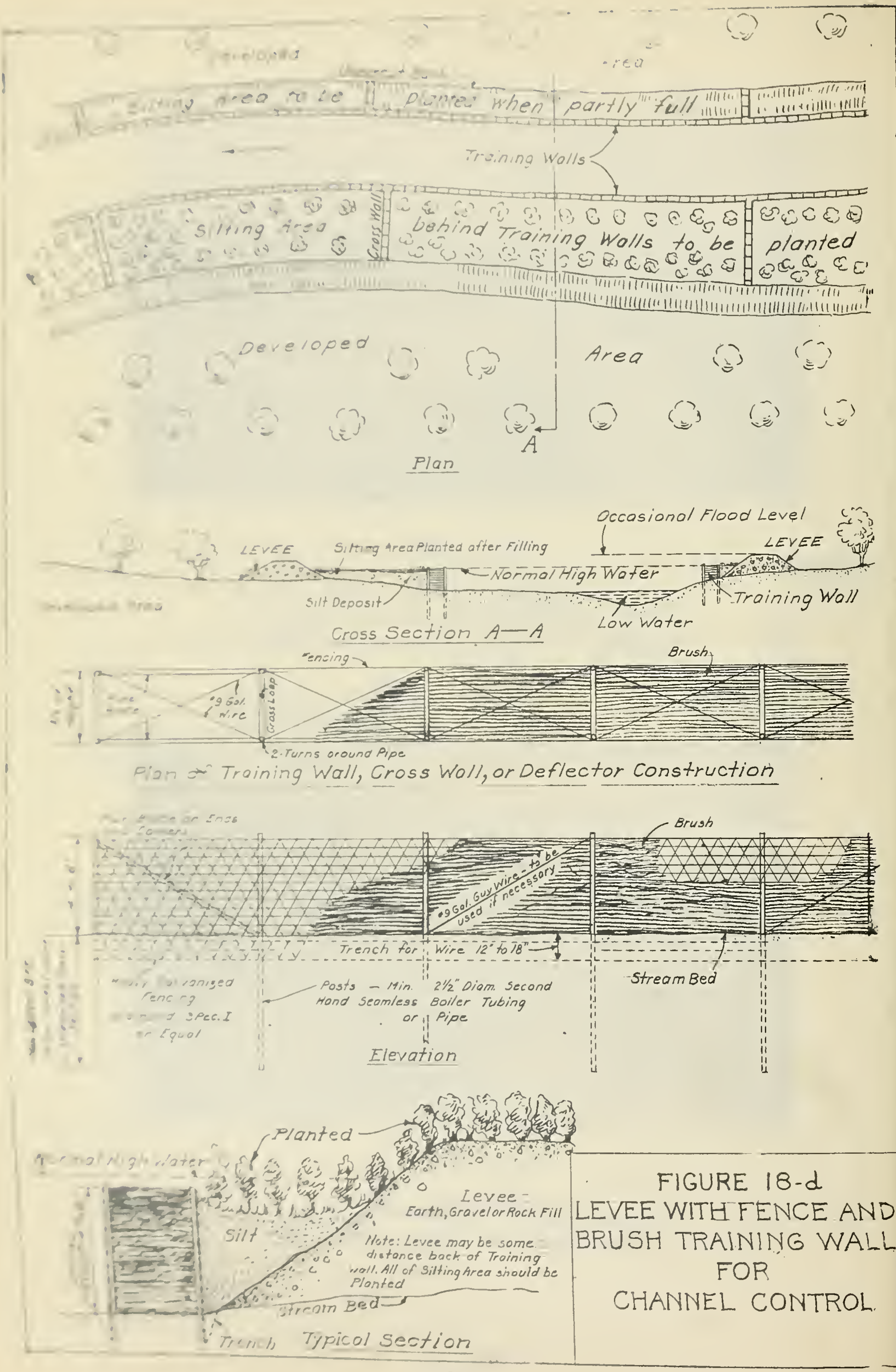


FIGURE 18-d
LEVEE WITH FENCE AND BRUSH TRAINING WALL FOR CHANNEL CONTROL

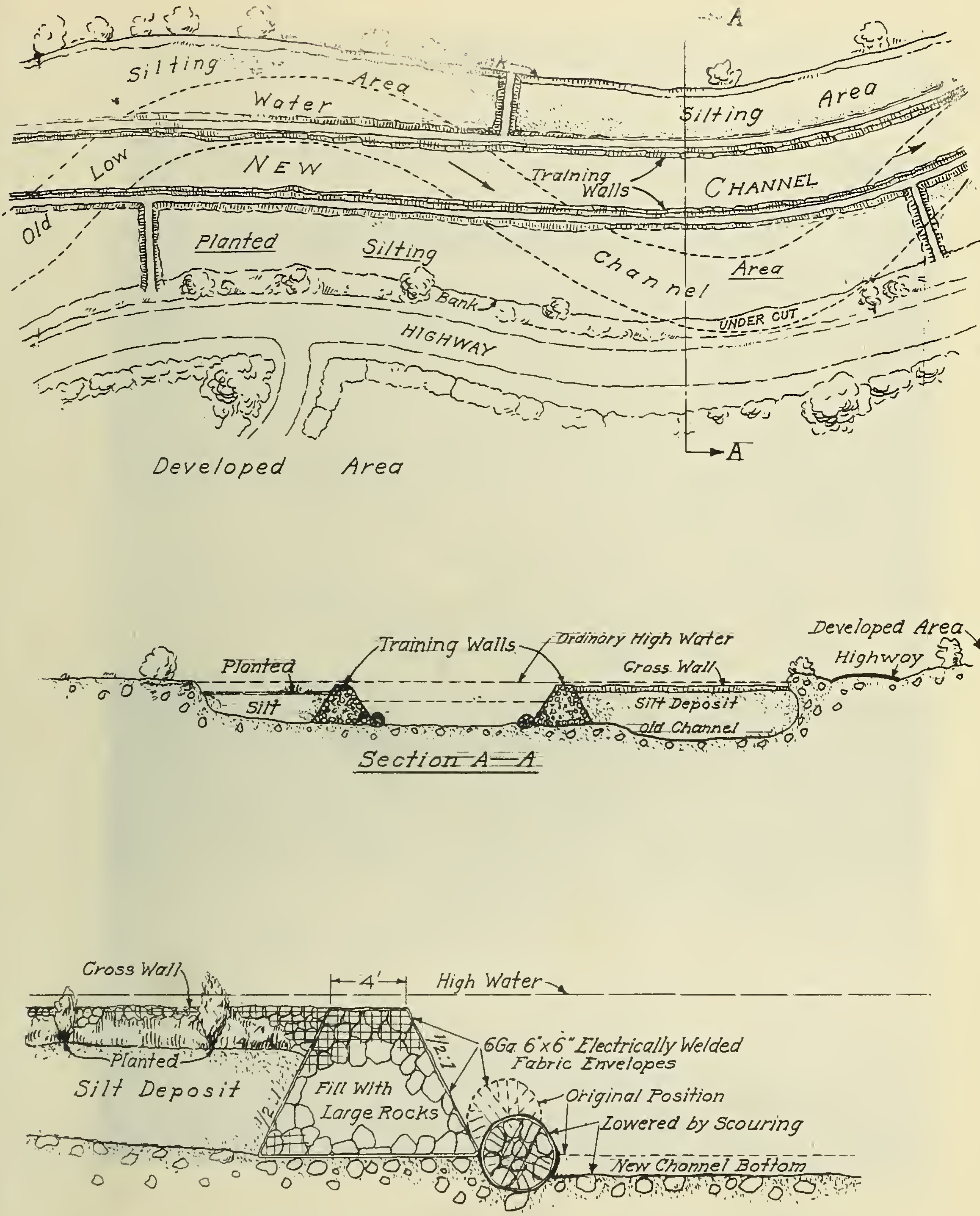


FIGURE 18-e
ROCK TRAINING WALLS
FOR
CHANNEL CONTROL

Figure 18f

Failure of rock and wire jetty where the flow was too swift and turbulent, resulting in greater damage.

Figure 18g

Another failure due to high velocity flow.

Figure 19

Fill slope on the San Gabriel Road, Angeles National Forest, California. Protected by brush wattles constructed by the California Forest Experiment Station.

The fascines are held in place with weighted cables which are slung across the top in each bay, as illustrated in Figure 18. The slings are made with 1/4 inch galvanized cable, having each end broomed out and embedded in a cubic foot block of concrete. After a few months use, it is usually necessary to remove the ballast cables and build up the brush fill to take care of settlement.

The penetration of the piles will depend on local conditions, but should be sufficient to provide security even after a large amount of erosion has taken place. The size and species of pile used will depend upon local factors. Since the tops of the piles will be subject to conditions which are favorable to decay, the use of species with good decay resistance qualities is of primary importance.

3. Continuous dikes. In some cases, rivers have cut into their banks extensively and have wide channels far in excess of the need as far as water capacity is concerned. The normal and low water flow courses back and forth across the channel, cutting further into the banks at various places. Under such conditions, restriction of the major stream to a limited central portion of the channel is feasible, for which purpose continuous longitudinal dikes are the obvious choice. They are usually supplemented by cross dikes to the river's banks at intervals to retard water velocities and aid in silt deposits. The same type of structure which is used for spur dikes meets the requirements for continuous dikes. Figure 18a shows the essentials of an installation of this kind. Figure 18b is a photograph of an installation on the Virgin River near Mt. Carmel, Utah, which has met with considerable success. A side view of one of these dikes, of rock and wire mesh construction, is shown in Figure 18c.

Another use for continuous dike protection occurs in relatively narrow, fast flowing rivers, where it is not feasible to cut back the bank for slope paving, as along valuable agricultural land, highways, and so forth. The toe of the caving bank can be protected by a continuous dike as in Figure 18a. As a rule this type of dike is subject to greater cutting action along its outer face, and should therefore be founded well below the depth of possible erosion.

Figures 18d and 18e show other variations of jetty construction, using different materials. It must be borne in mind that the useful life of any type is dependent upon the life of the material of which it is made.

The photographs shown in Figures 18f and 18g illustrate the result of construction of a wire basket and rock jetty where conditions were not at all suited to it. The jetty obstructed a large percentage of the water area and so forced an increase in the velocity, which was already so high that it was eroding the gully. The increased velocity also increased the transporting force of the water and so aggravated a condition already bad. The remedy for the restoration of the gully shown in these two photographs is not to be found in the channel control methods of this Section, but rather in the use of gully control devices described in Chapter IV.

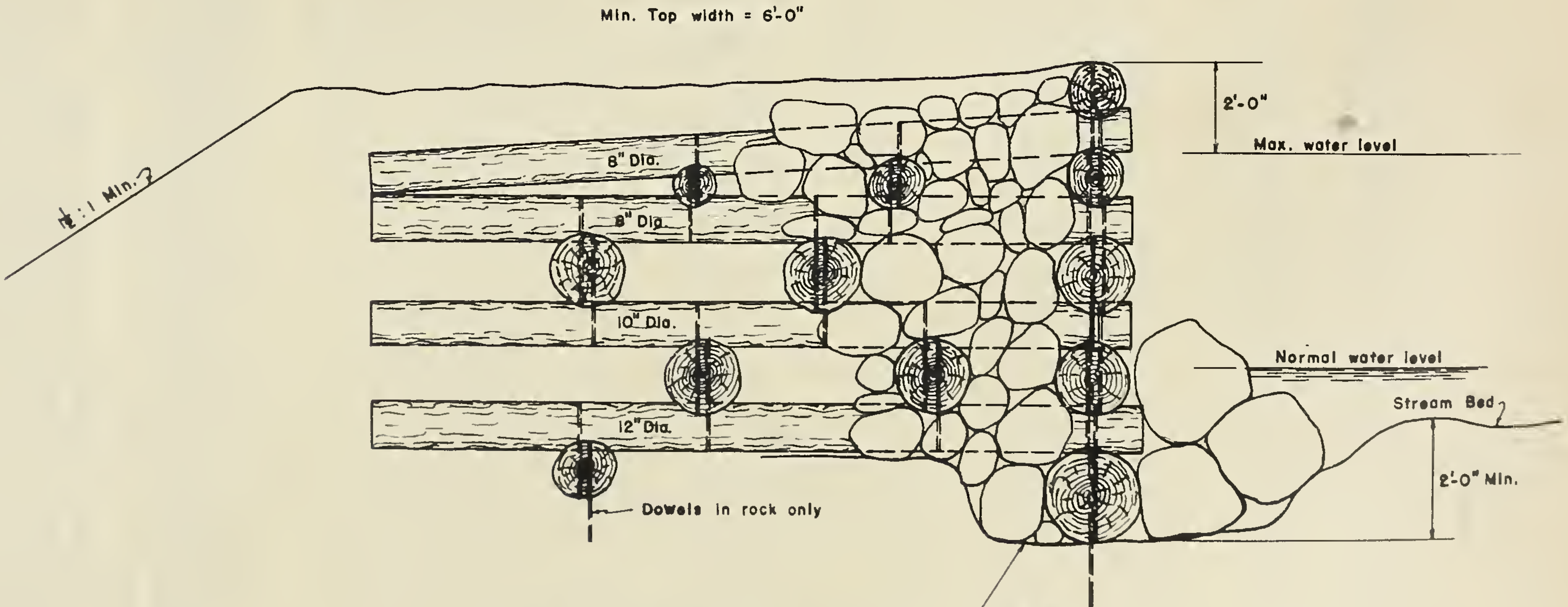
14. Road Fills and Cuts.

Road-bank protection is not within the scope of this handbook. Detailed information on the subject will be included in the Truck Trail Handbook.

Both the Appalachian Forest and Range Experiment Station and the California Forest and Range Experiment Station have done a large amount of research on road-bank protection and they should be consulted on such work to obtain the latest developments in vegetative control.

Figure 19 shows a fill slope on the San Gabriel Road, Angeles National Forest, California, which has been protected by means of measure i - brush wattles, which held the loose soil in place and allowed the green stakes driven into the wattles and the wattles themselves to sprout and grow. Note in this picture that a good growth of vegetation has begun. These measures are particularly effective on high fill slopes where there is danger of sliding and where the rainfall is light.

Measures g, planting, and h, mulching, are also effective for road-bank protection where there is sufficient rainfall to give the vegetation a quick start. In the Appalachian Mountains good results have been had by planting honesuckle and other quick-growing vines. They are usually planted in pockets which have been dug out of the cut bank and filled with top soil.



TYPICAL SECTION OF CRIB

Scale 2'-0" = 1"

Typical Rock-fill Timber Crib Dike

Rock-fill, timber crib dike to protect Campton Forest Camp, White Mountain National Forest, from Mad River.

Bottom logs are four feet below river bed, and top logs three feet above known high water.

Small stones between logs and large "derrick" stones along front of dike taken from river channel.

Logs are peeled and tied together with 1-inch iron pins. Enduring species of wood were selected. Native materials permit low cost.

Typical Crib Deflector

The river discharge approaches this deflector [illegible] angle of about 45 degrees, and is directed toward a stone cliff, [illegible] protecting the flat Camp area behind the crib. An auxilli[illegible]rallels the channel below the deflector. Deflector angles [illegible]cal conditions - are usually less abrupt than this.

The upstream end of the crib is deeply anch[illegible]ded with cut off to prevent erosion behind the cribbing.

The crib section is designed with allowance [illegible] so that it can be over topped without damage.

Close up of Rock-fill Cribbing Construction

Note fitted, staggered joints which are pinned with 1-inch iron dowels.

Small deflector just upstream from bank-protection crib dike to prevent erosion behind dike. Small amount of leakage through this structure is expected and desirable. Where deflectors or jetties are of sufficient importance and size, model tests are justified.

Chapter III

HYDRAULICS OF EROSION CONTROL

15. Estimating Probable Run-Off.

If 1 inch of rain runs off uniformly in 1 hour without loss, each acre of the watershed will yield 1 second-foot of run-off. In some cases a combination of conditions, such as the shape and topography of the drainage area, the pattern of the tributary streams, and the direction of the storm, will unite to give a yield at some point that may be somewhat greater. Ordinarily, however, absorption, percolation, and surface storage will reduce the yield so that the ratio of run-off to rainfall is less than unity. Such factors as density of vegetative cover, kind of soil, moisture content of the soil before the storm, slope of the watershed, and intensity of the rainfall—all have a somewhat indeterminate effect on the run-off factor, which is the ratio of run-off to rainfall. It is obvious that this factor will vary widely on different watersheds and in different parts of the country. Any attempts to develop formulae or ratios for widespread application are bound to give results of doubtful value for specific small areas. The best estimate is usually made from a knowledge of the various conditions mentioned above, a study of former flows, and a background of understanding of the principles of flood occurrence and prediction.

High stream flows are produced by heavy rains, melting snow, or sometimes a combination of both. In the parts of the country which have been most seriously damaged by water erosion, the trouble has been caused by run-off from severe rainstorms, and it is therefore this type of flood that we are particularly interested in. It is well known that the size of the largest annual flood varies from year to year, and that the maximum flood of any one year has no definite relation to that of any other year. If records are available for a period of several years, the average of the figures representing the biggest flow for each year will give the average maximum annual flood. Floods of this size or greater can be expected one-half, or 50 percent, of the time, although for several successive years the year's greatest flow may be either consistently smaller or consistently larger than this average. In the long run, the number of years in which this flood is exceeded will equal the number of years in which it is not.

For floods of greater amount but less frequent occurrence, the study of long-time records will indicate the probable frequency with which they can be expected. That is to say, a certain flood flow can be expected once in 10 years, a larger one once in 50 years, and so on. This does not mean that anyone has reason to predict that the so-called 10-year flood will actually be exceeded every 10 years, but rather that over several 10-year periods the annual maximum will exceed it about 10 percent of the time. Since it is rainfall which causes the flood flows, the same laws are used for rainfall anticipation when streamflow records are not available.

Because most of the erosion control work will be on small watersheds which do not support continuous streams, there will seldom be any useful information as to actual flow records. For this reason, we are usually forced to rely on a comparison with other larger areas, or to computation from rainfall records. In that part of the country east of the one hundred and fifth meridian, a combination of good records and more or less uniform rainfall characteristics has made it possible to predict run-off volume with fair accuracy. The method presented here is taken from the 1916 edition of Meyer's "Hydrology," with charts given by Ramser in the United States Department of Agriculture bulletin "Brief Instructions on Methods of Gully Control."

The curves on page 29 give the run-off from areas ranging from 1 to 1,000 acres for two different slope conditions, and for three types of soil cover. These data are for the area marked "zone 3" on the map on

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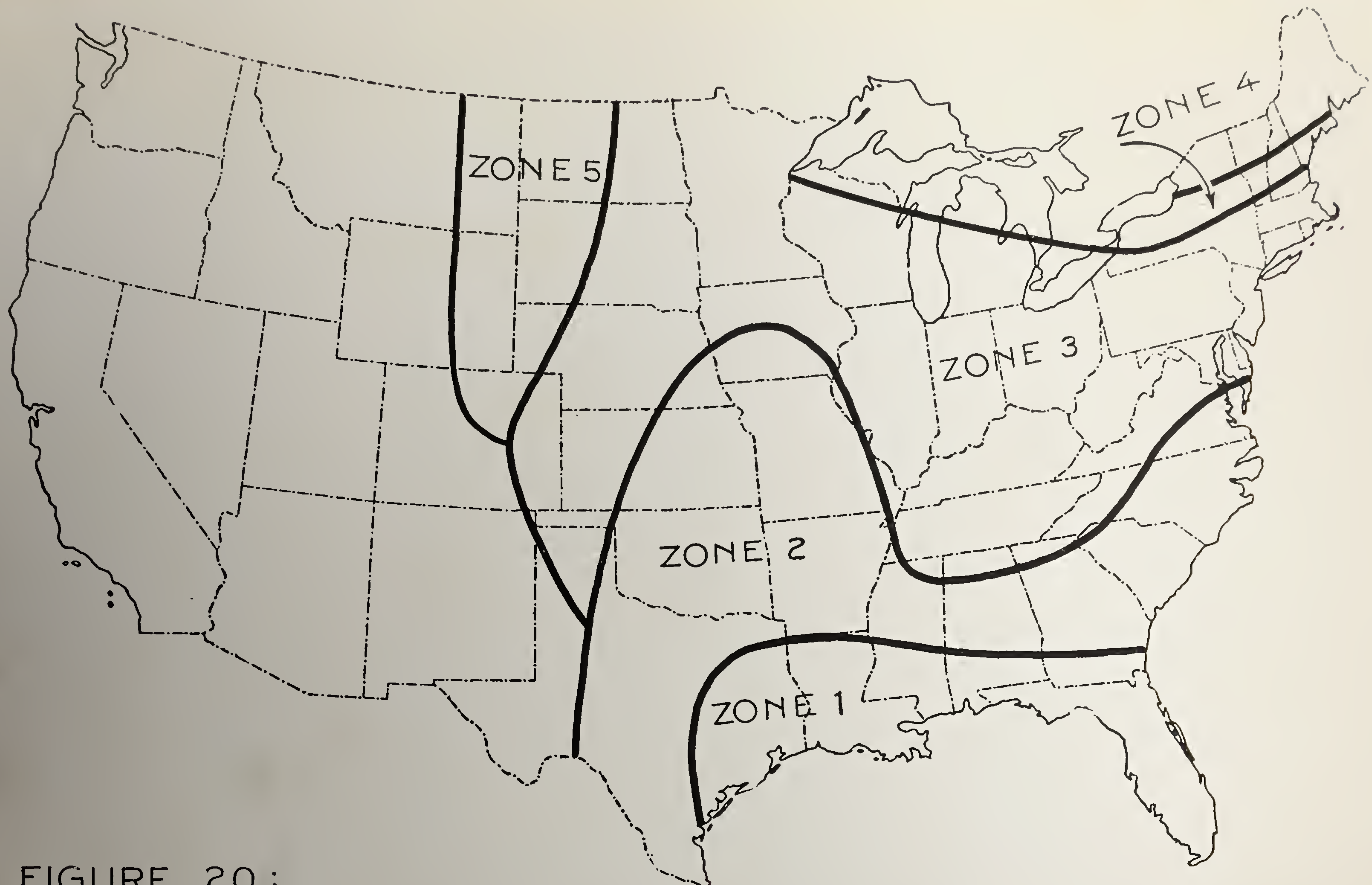
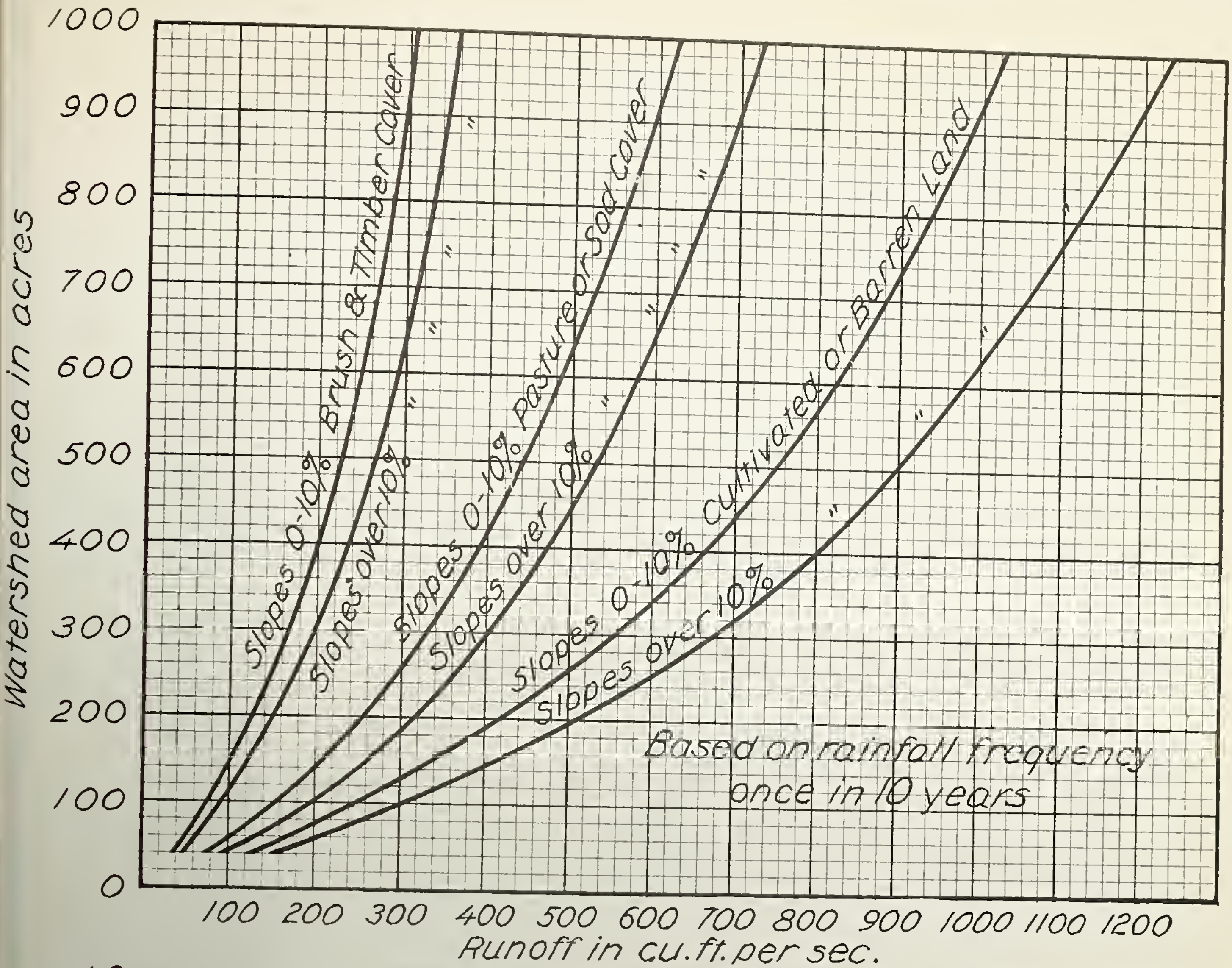
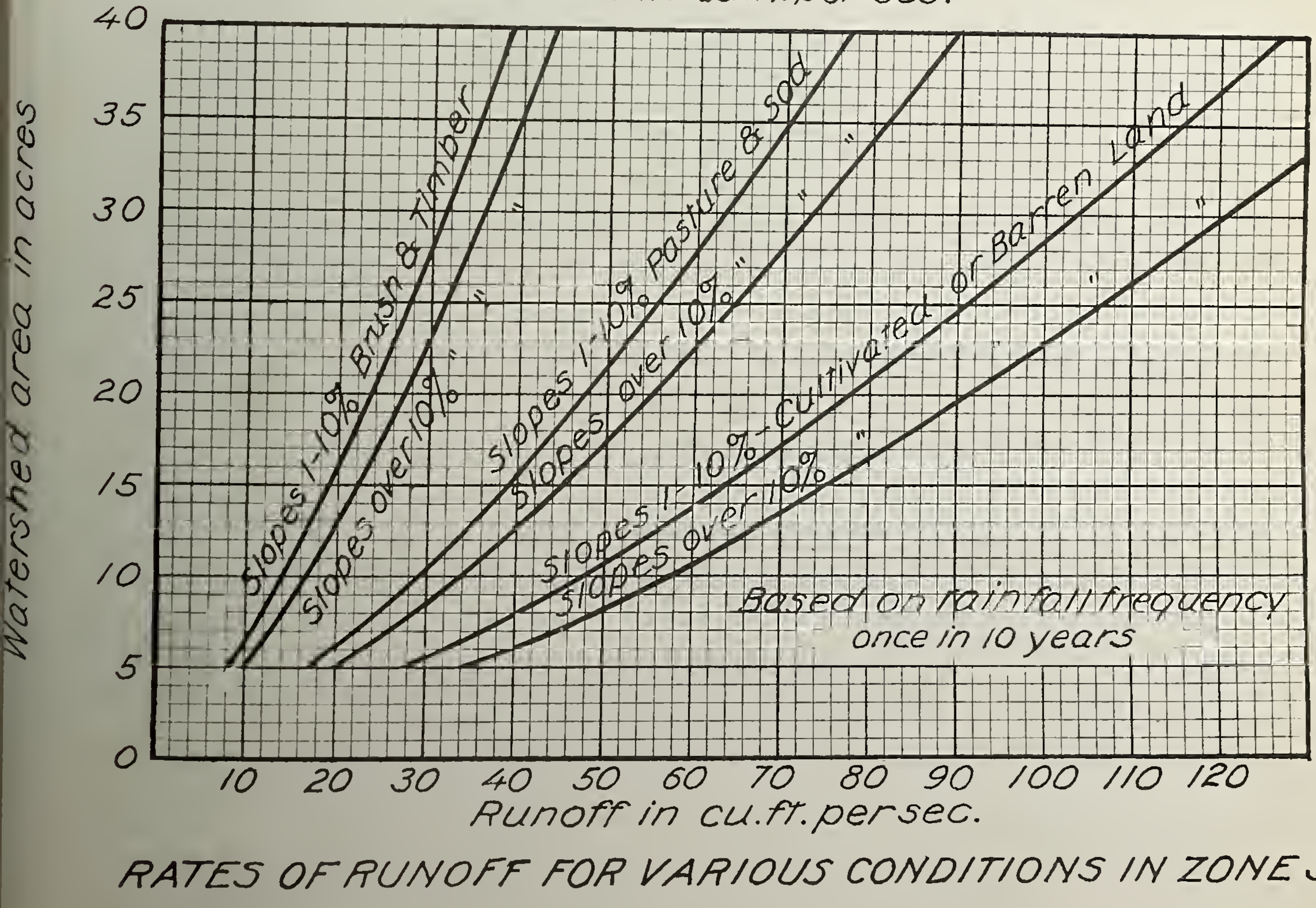


FIGURE 20:
BOUNDARIES OF AREAS OF SIMILAR RAINFALL INTENSITIES FOR SHORT PERIODS (From Meyer's Hydrology)

See section 15 of text for area beyond western limits of zones 2, 3, and 5





RATES OF RUNOFF FOR VARIOUS CONDITIONS IN ZONE 3

FIGURE 21

page 28, and are based on a rainfall frequency of once in 10 years. Table II below, gives factors for converting the 10-year figures to those of 2-, 5-, and 25-year expectancy. These conversion factors vary for the different zones, as seen from the table.

As a general rule, it is recommended that erosion control structures be designed for the 10-year floods. However, in the southeastern part of the country (zone 1, and parts of zones 2 and 3), where the precipitation is high and the growing season is long, this requirement can be modified in some cases. If the corrective treatment includes planting of trees and vines and seeding of sod-producing plants, the vegetative recovery will be rapid enough to bind the soil within 2 or 3 years time, after which the minor erosion structures will not be needed. Under these conditions, the engineering structures can be designed to carry only the average annual flood, or the flow which can be expected 50 percent of the time.

In this same section, if the run-off is controlled but no planting is done, natural vegetative recovery on reasonably good soils can be expected within 4 or 5 years, and structures designed for a 5-year flood will probably be adequate. For other conditions less favorable to vegetative recovery, the 10-year flood requirement should be followed.

TABLE I.—*Ratio of rainfall intensity in zones 1, 2, 4, and 5 to zone 3 for 10-year frequency*

[From Meyer's Elements of Hydrology, first edition]

Area in acres	Zone			
	1	2	4	5
1	1. 15	1. 08	0. 90	1. 02
10	1. 22	1. 12	. 90	. 97
50	1. 29	1. 16	. 89	. 89
100	1. 34	1. 19	. 89	. 86
200	1. 42	1. 23	. 89	. 83
400	1. 50	1. 27	. 89	. 80
600	1. 55	1. 30	. 88	. 78
800	1. 58	1. 32	. 88	. 76
1,000	1. 62	1. 33	. 88	. 75

TABLE II.—*Ratio of rainfall intensity of other frequencies to the 10-year value*

Zone	Frequency		
	2 years	5 years	25 years
1	0. 75	0. 86	1. 17
2	. 70	. 87	1. 18
3	. 65	. 83	1. 17
5	. 61	. 84	1. 28

The first step in making a run-off estimate is a survey of the watershed, determining the area, the average slope, and if it includes different kinds of cover, the areas of each kind should be measured or estimated. As an example, assume that we have in Mississippi an area of 125 acres of hilly ground on which the average slope exceeds 10 percent. There are 60 acres covered with dense brush and woods, 15 acres of pasture or sod-covered land, and the balance of 50 acres was once under cultivation but is now badly eroded and bare of vegetation. From figure 21 on page 29 we find that in zone 3, the run-off from 125 acres on slopes exceeding 10 percent is—

	Cubic feet per second
125 acres of woods	108
125 acres of pasture	232
125 acres of cultivated	362

Reducing to the proportionate amounts of each type of cover, we get—

	Cubic feet per second
$^{60}/_{125}$ of 108	48
$^{15}/_{125}$ of 232	28
$^{50}/_{125}$ of 362	145
Total	221

This 221 cubic feet per second total is the zone 3 run-off from this area on a 10-year basis. Table I on page 30 gives a factor of 1.20 for converting zone 3 to zone 2 on a watershed of 125 acres. The zone 2 run-off is therefore $221 \times 1.20 = 265$ cubic feet per second for the 10-year flood. To reduce this to the 5- or 2-year flow, consult table II and multiply by the factor given there.

In the Rocky Mountain district, the precipitation varies widely in different sections, depending on altitude, slope exposure, and other local influences. In some sections the highest flows are from melting snow in the spring, and in others the greatest seasonal flow is from summer rains. It is usually the run-off from the latter type of storm which must be controlled to prevent erosion. One of the characteristics of these storms is that they do not cover large areas, and since rain gages are widely separated, rainfall records of many of them are not obtained. Because of lack of records, both of rainfall and run-off, there is no proven basis for predicting the frequency and intensity of run-off from the small drainage areas which erosion structures control.

Under the title of "Rainfall Intensity—Frequency Data", David L. Yarnell, of the Bureau of Agricultural Engineering, has presented in United States Department of Agriculture Miscellaneous Publication No. 204, data worked up from all recording type rain gages in the United States. Particular attention was given to rain of high intensity and short duration, most of which runs off as surface water with little loss from percolation or infiltration.

Unfortunately recording rain gages were widely separated in the West, with only two in each of the States of Arizona, New Mexico, and Utah, and three each in Idaho, Colorado, and Nevada. It is probable that there were many storms of equal or greater intensity than those which occurred at the recording gages, and which are not included in the compilation. It is also true that there are local areas between these stations in which rainstorms do not have the intensity or frequency indicated by the Yarnell charts. However, this information, if used by an engineer familiar with local conditions, will serve as a valuable guide in the Rocky Mountains.

For small watersheds of less than a thousand acres, the rational method of computing run-off from the predicted rainfall is recommended. The equation is $Q=CIA$, where Q is the rate of run-off in cubic feet per second; C, the run-off factor, is a decimal representing the portion of the rainfall that appears as run-off; I is the rate of rainfall in inches per hour; and A is the drainage area in acres.

The frequency factor is taken care of through the value of I, using the average annual value for storms of 2-year frequency, the 5-year value for storms of 5-year frequency, and so on. Pages 32 to 41 give Yarnell's charts for 5-, 10-, 15-, 30-, and 60-minute periods at expectancy intervals of 2, 5, 10, and 25 years.

In the semiarid sections of the West, where the growing season is relatively short and growing conditions not favorable, the ordinary erosion control structures for temporary use should be designed to handle floods of the estimated 10-year frequency. If the affected area is to be planted and there is good reason to believe growth will be rapid, structures designed for 5-year floods will probably last until the vegetation can control the situation. For the permanent structures, frequencies of 25 or 50 years should be used, depending on the size and importance of the project.

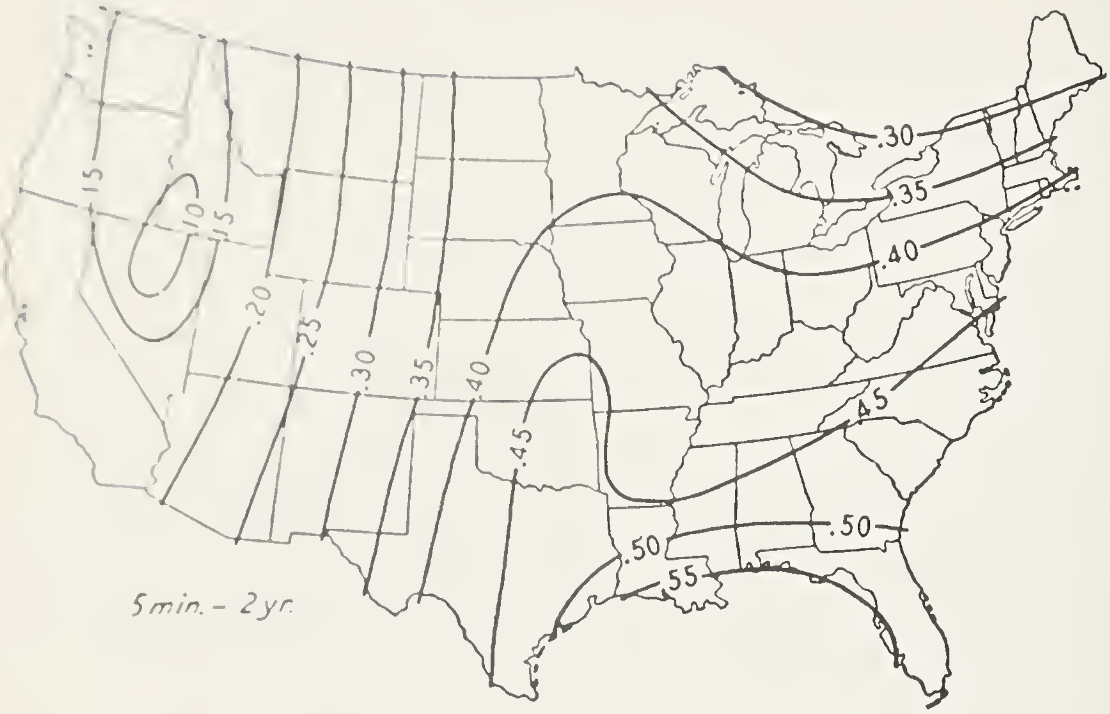


FIGURE 22.—Five-minute rainfall, in inches, to be expected once in 2 years.

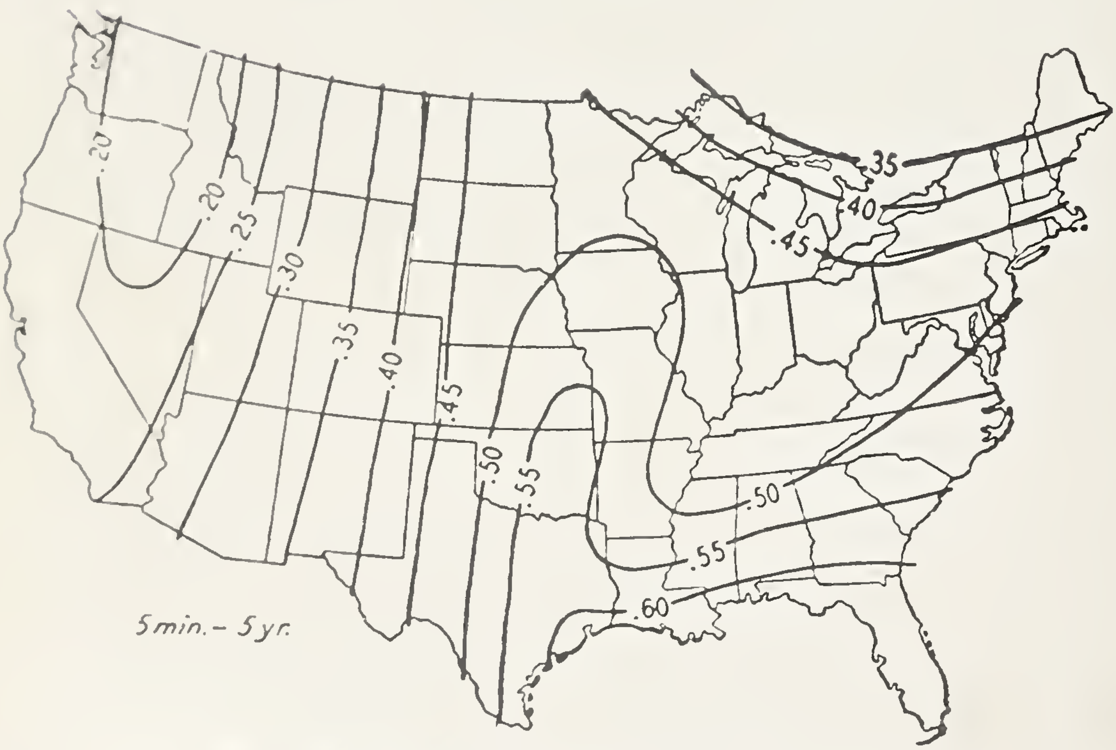


FIGURE 23.—Five-minute rainfall, in inches, to be expected once in 5 years.

[Taken from Misc. Pub No. 204, U. S. Dept. of Agriculture]

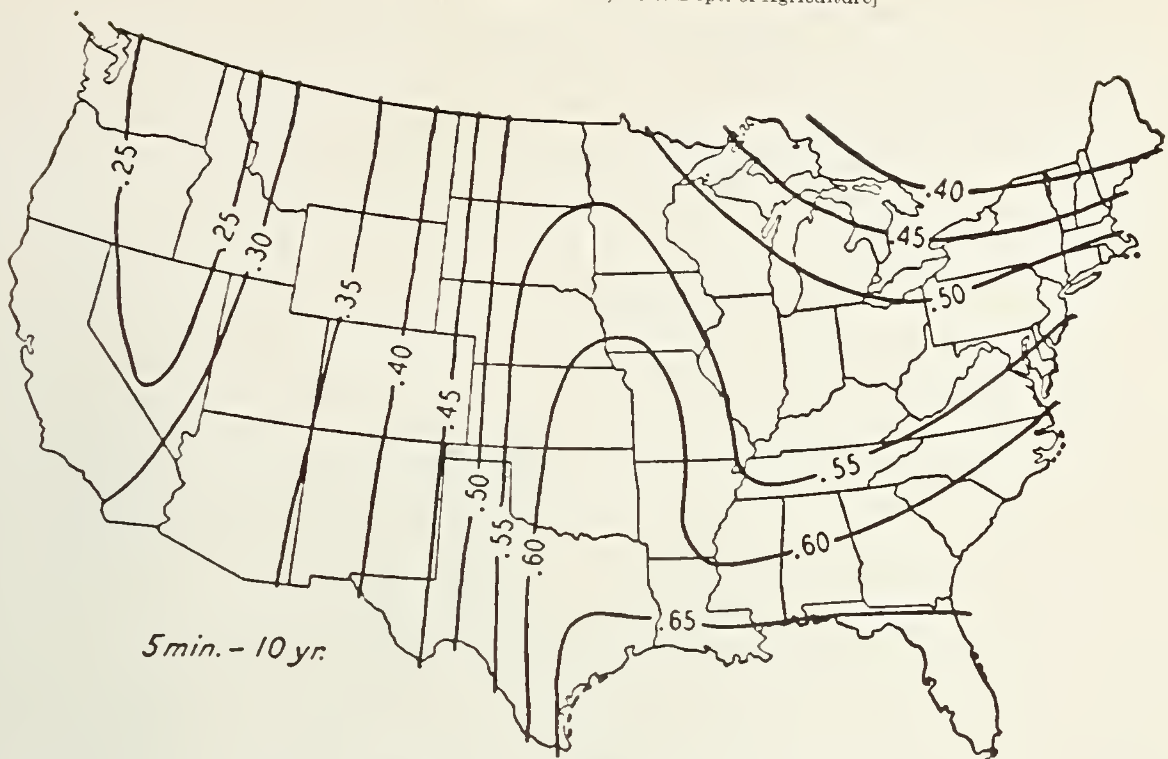


FIGURE 24.—Five-minute rainfall, in inches, to be expected once in 10 years.

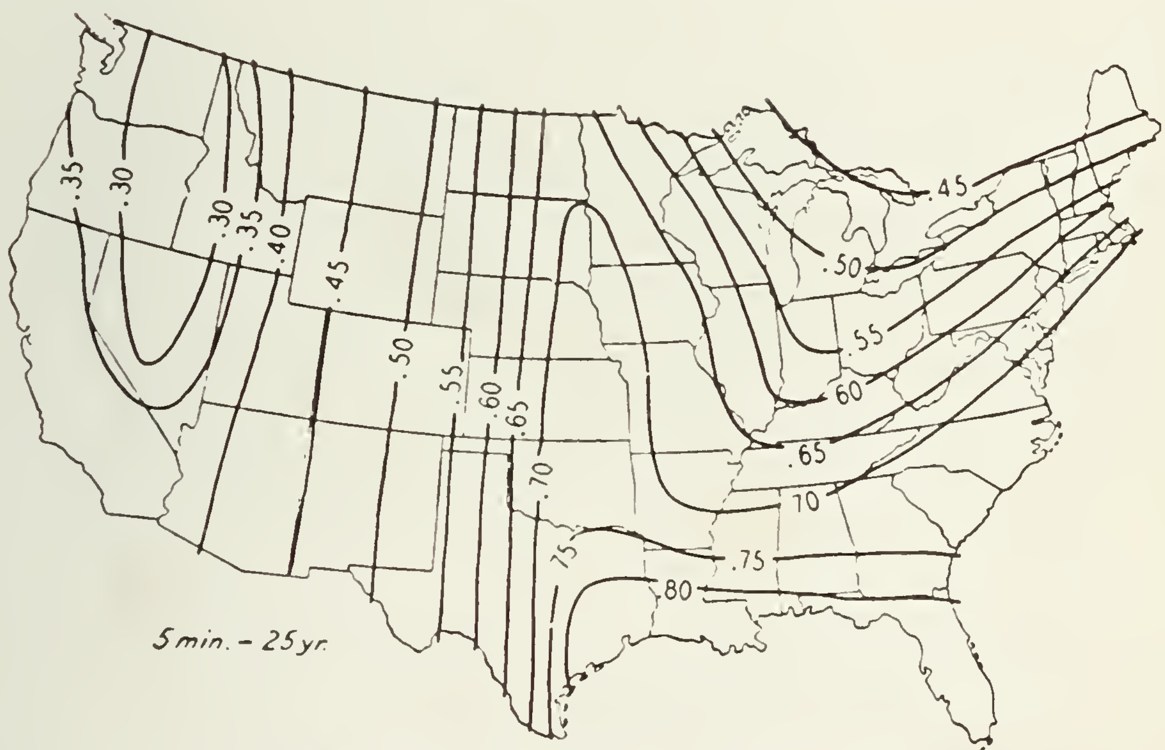


FIGURE 25. Five-minute rainfall, in inches, to be expected once in 25 years.

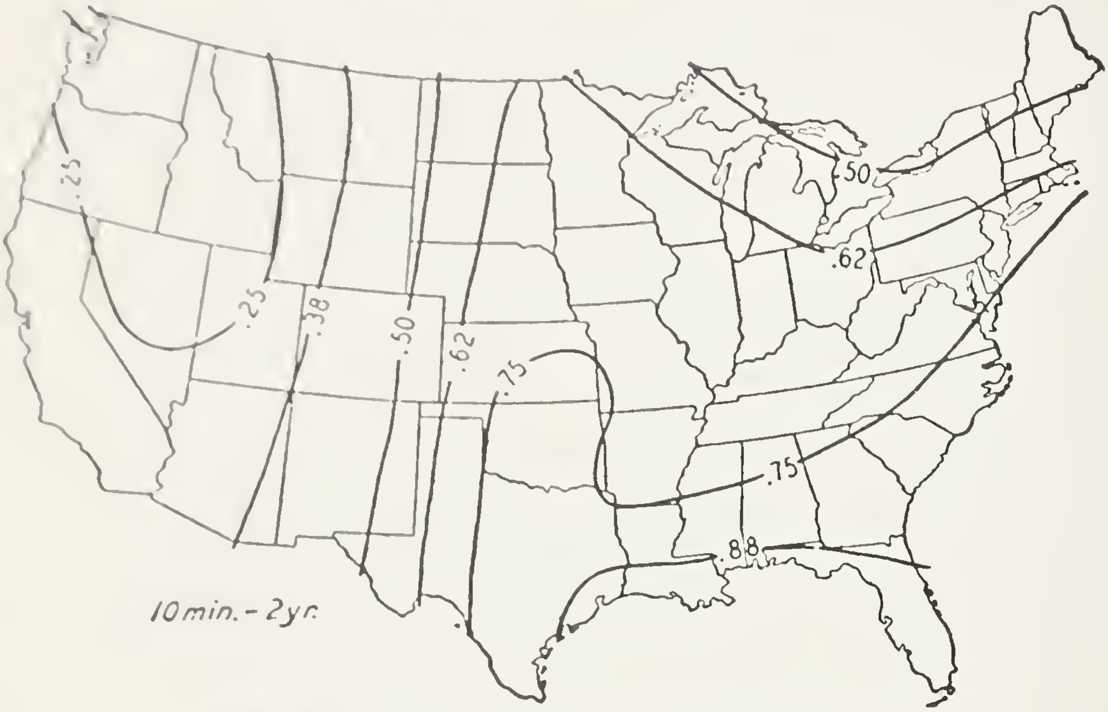


FIGURE 26.—Ten-minute rainfall, in inches, to be expected once in 2 years.

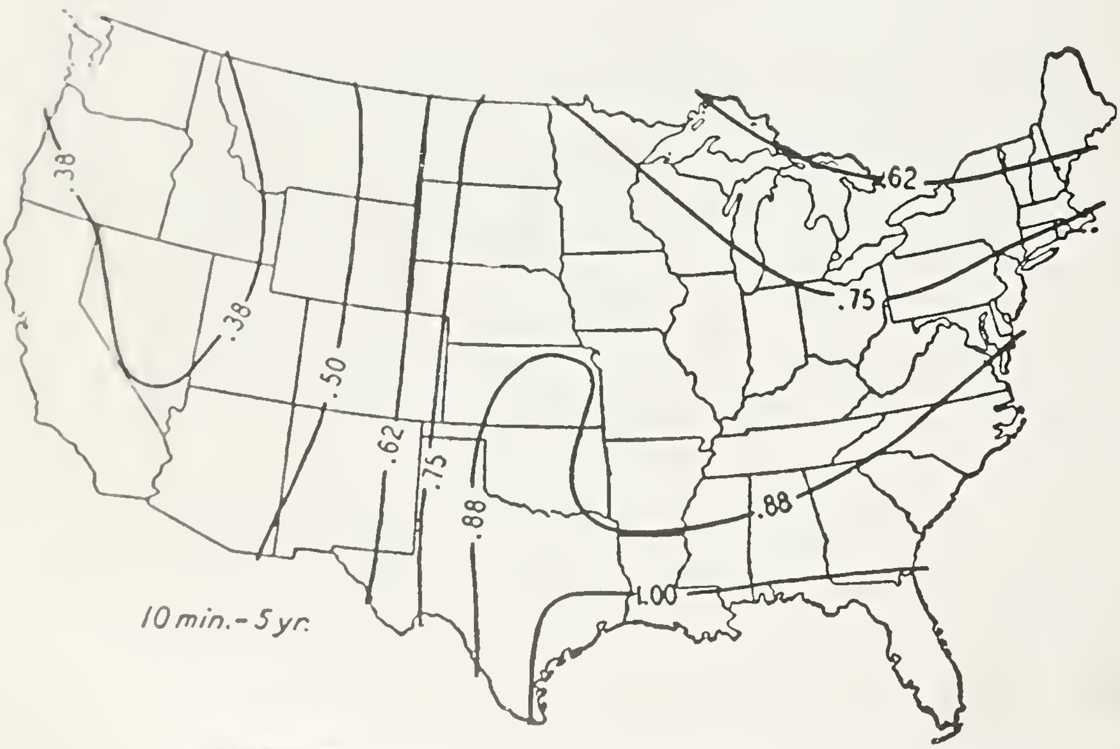


FIGURE 27.—Ten-minute rainfall, in inches, to be expected once in 5 years.

[Taken from Misc. Pub. No. 204, U. S. Dept. of Agriculture]

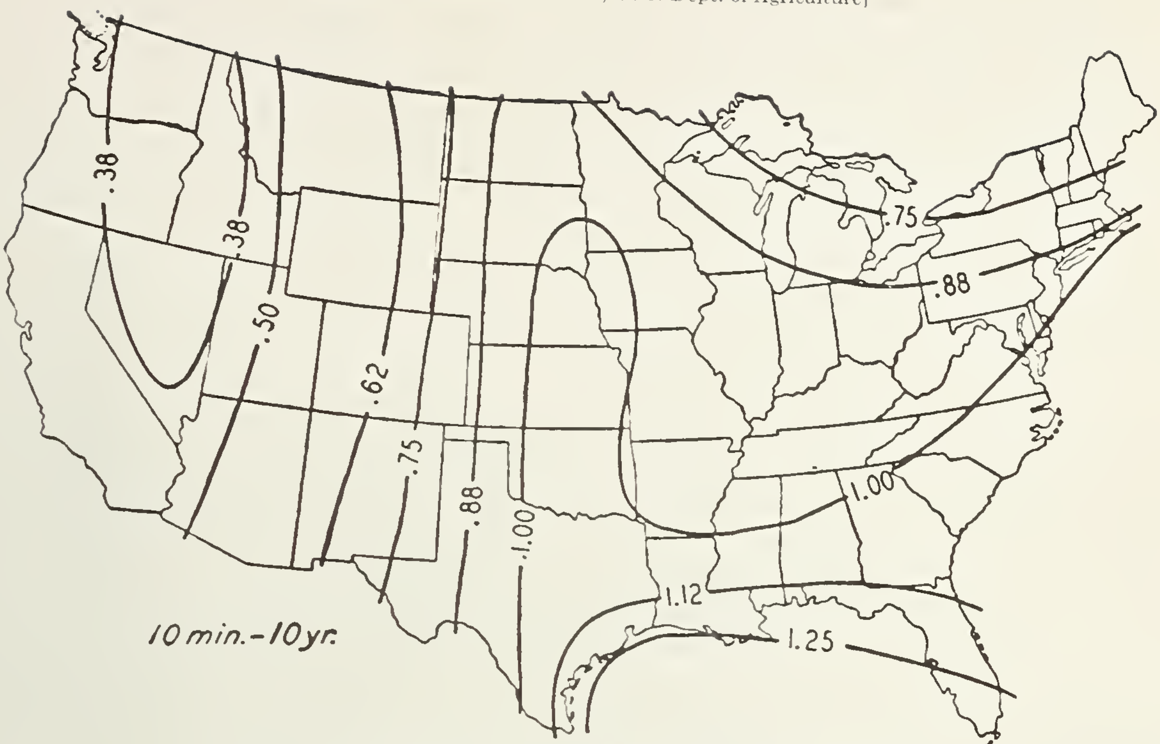


FIGURE 28.—Ten-minute rainfall, in inches, to be expected once in 10 years.

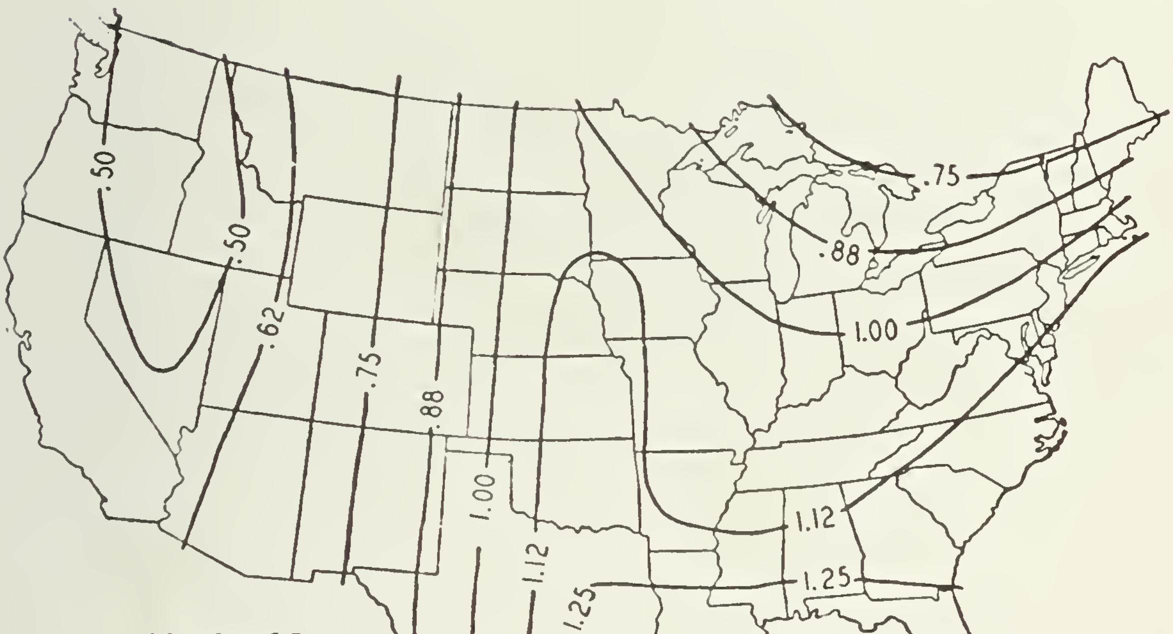


FIGURE 29.—Ten-minute rainfall, in inches, to be expected once in 25 years.

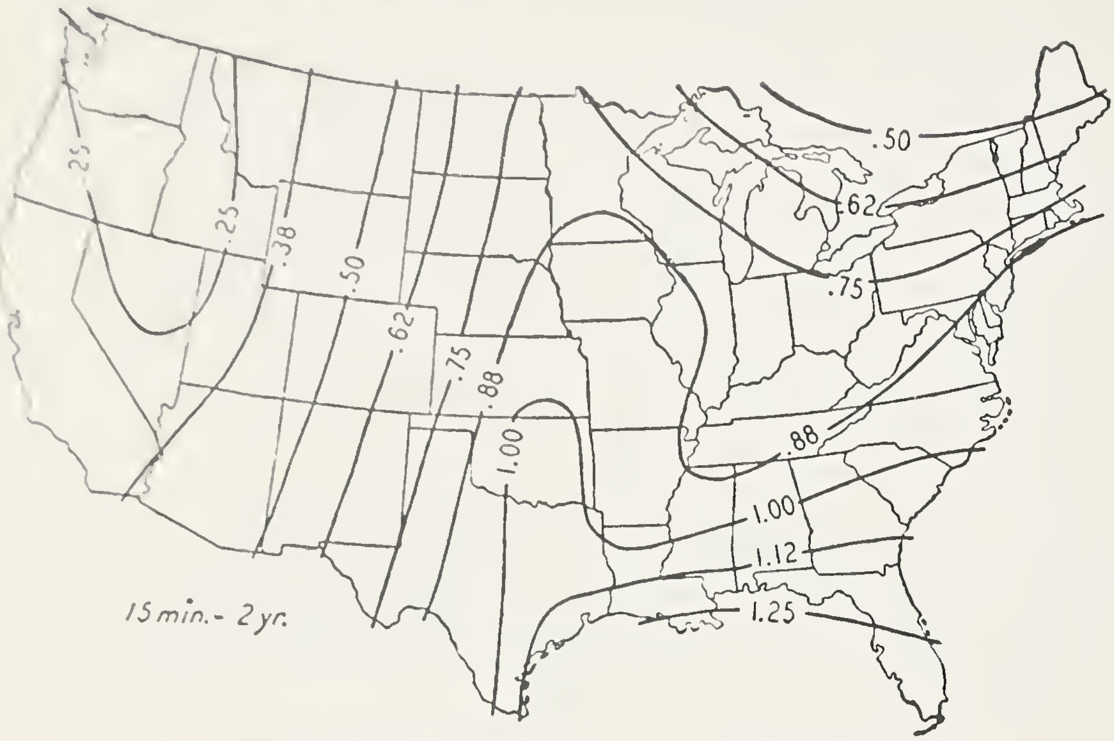


FIGURE 30.—Fifteen-minute rainfall, in inches, to be expected once in 2 years.

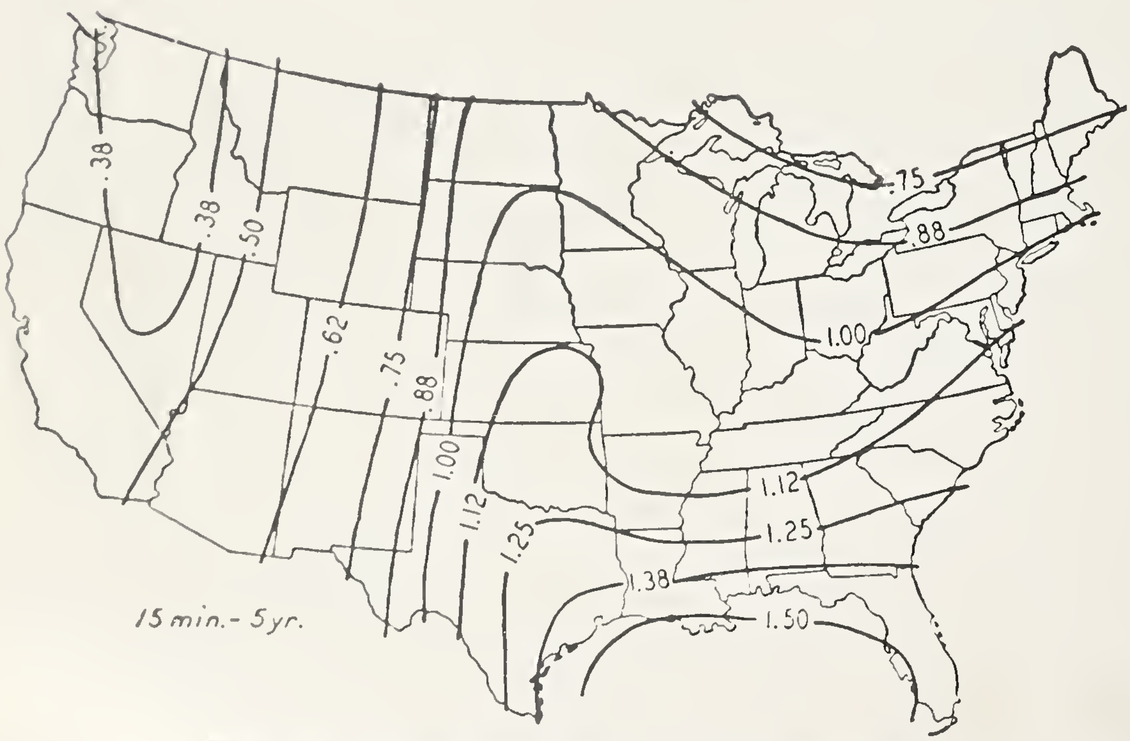


FIGURE 31.—Fifteen-minute rainfall, in inches, to be expected once in 5 years.

[Taken from Misc. Pub. No. 204, U. S. Dept. of Agriculture]

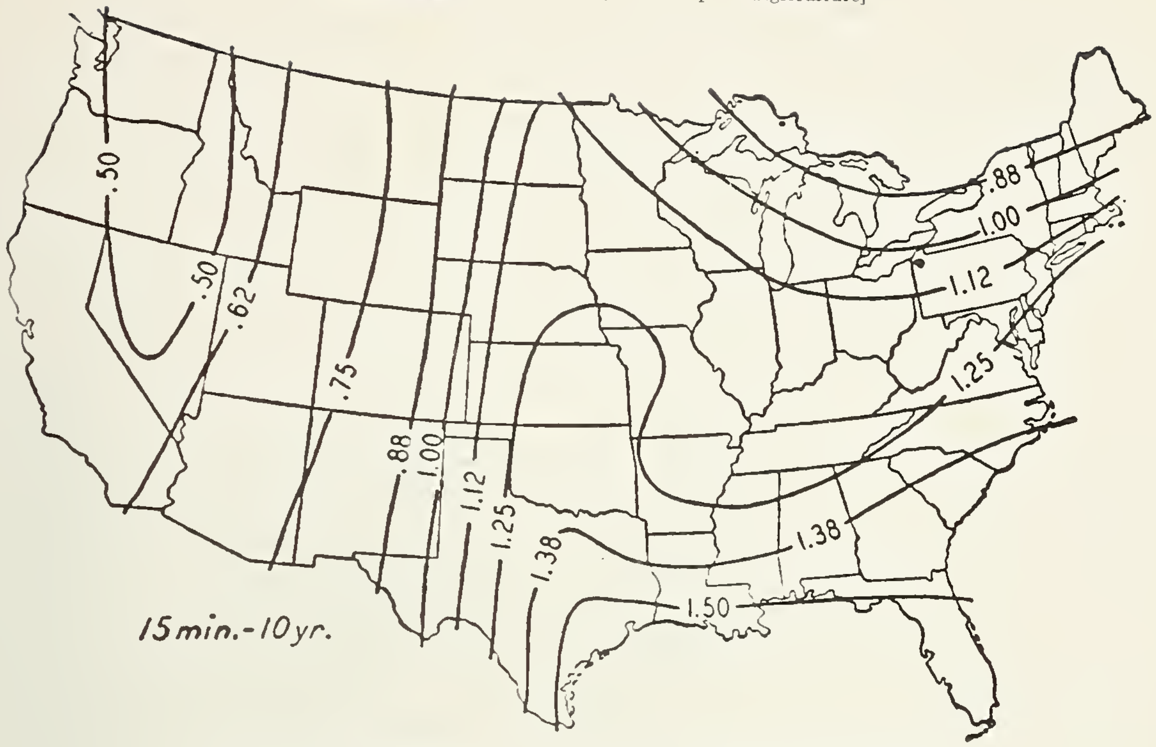


FIGURE 32.—Fifteen-minute rainfall, in inches, to be expected once in 10 years.

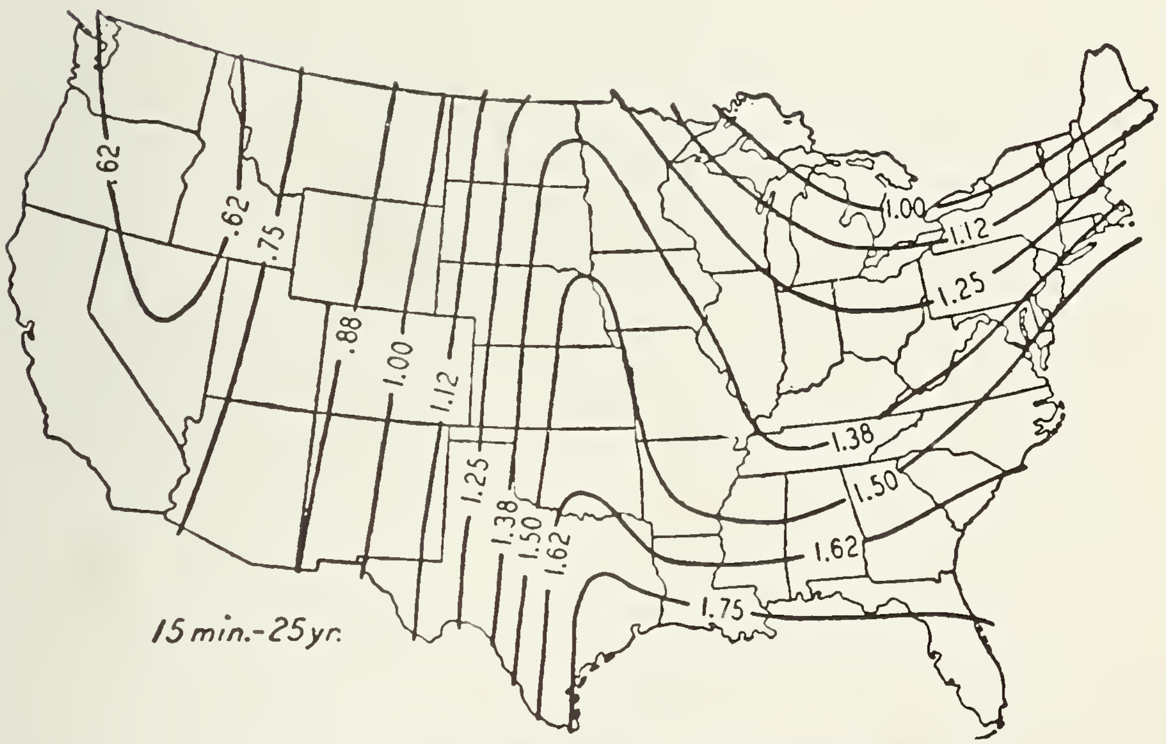


FIGURE 33.—Fifteen-minute rainfall, in inches, to be expected once in 25 years.

[Taken from Misc. Pub. No. 204, U. S. Dept. of Agriculture]

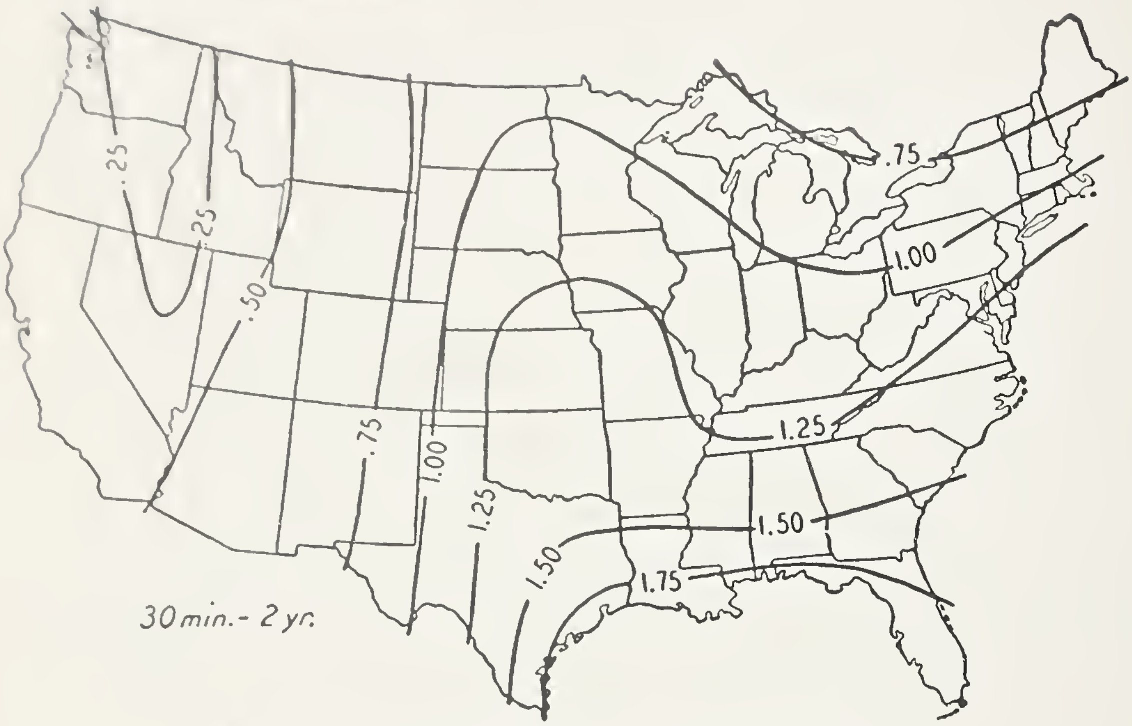


FIGURE 34.—Thirty-minute rainfall, in inches, to be expected once in 2 years.

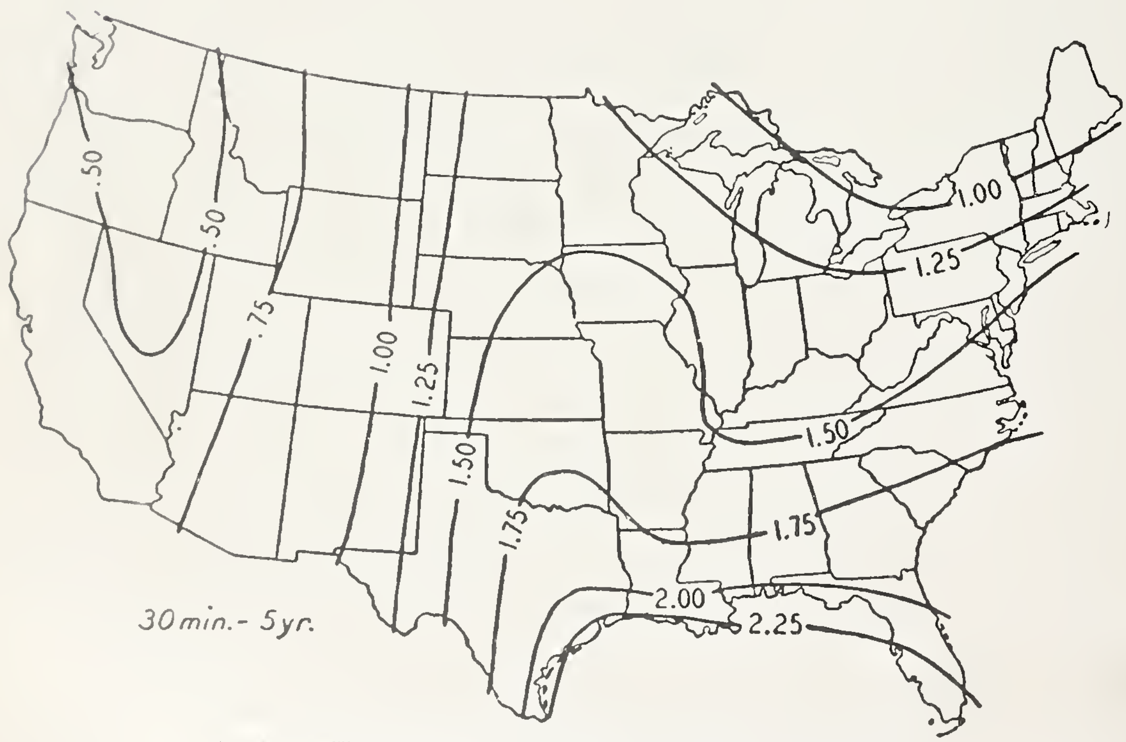


FIGURE 35.—Thirty-minute rainfall, in inches, to be expected once in 5 years.

[Taken from Misc. Pub. No. 204, U. S. Dept. of Agriculture]

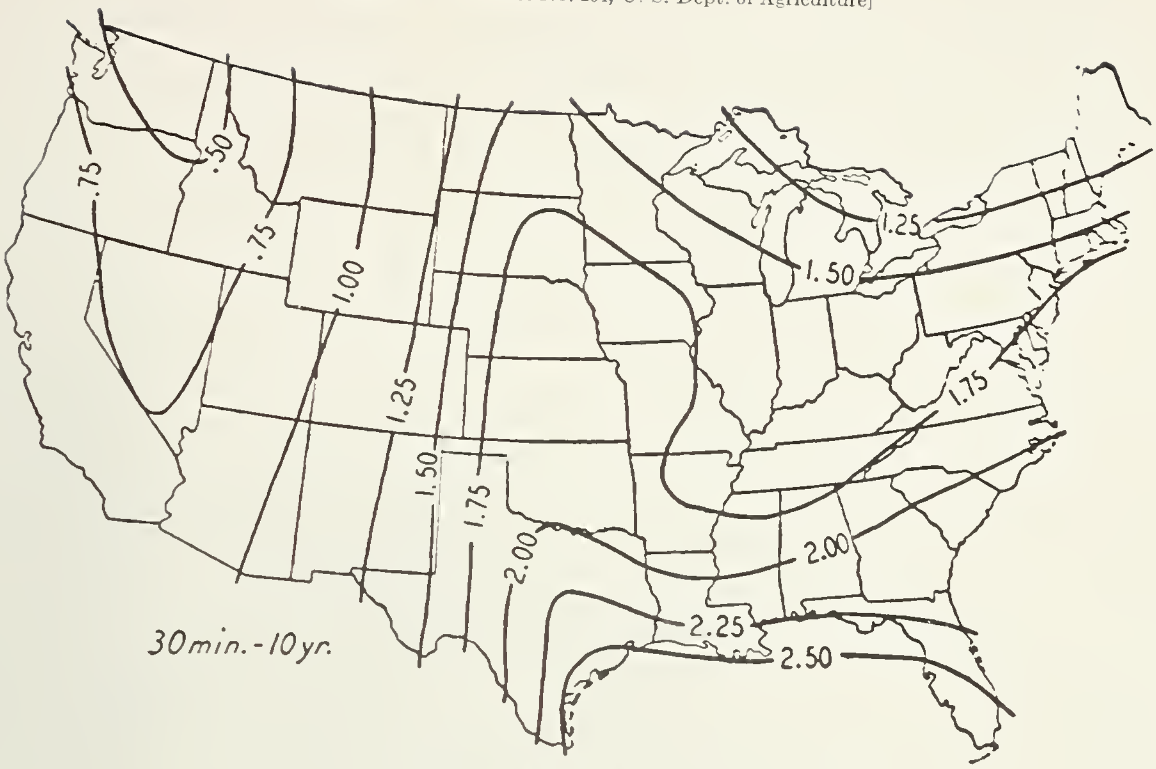


FIGURE 36.—Thirty-minute rainfall, in inches, to be expected once in 10 years.

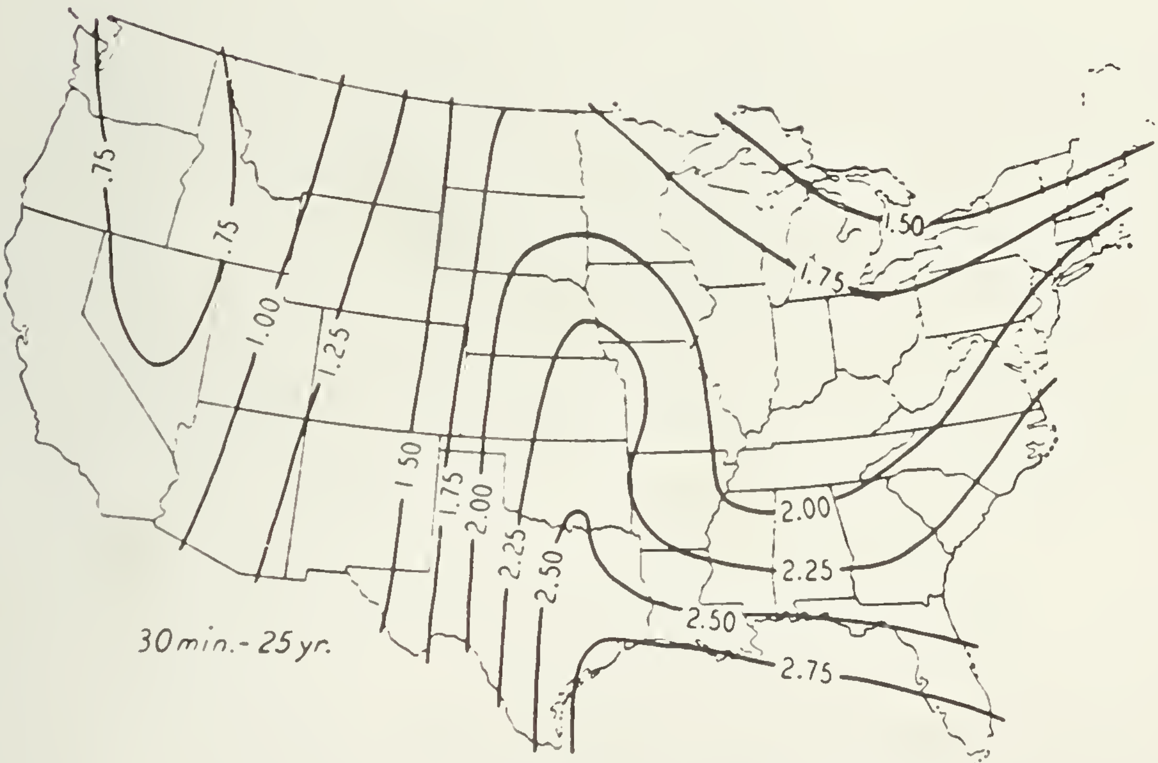


FIGURE 37. Thirty-minute rainfall, in inches, to be expected once in 25 years.

[Taken from Misc. Pub. No. 204, U. S. Dept. of Agriculture]

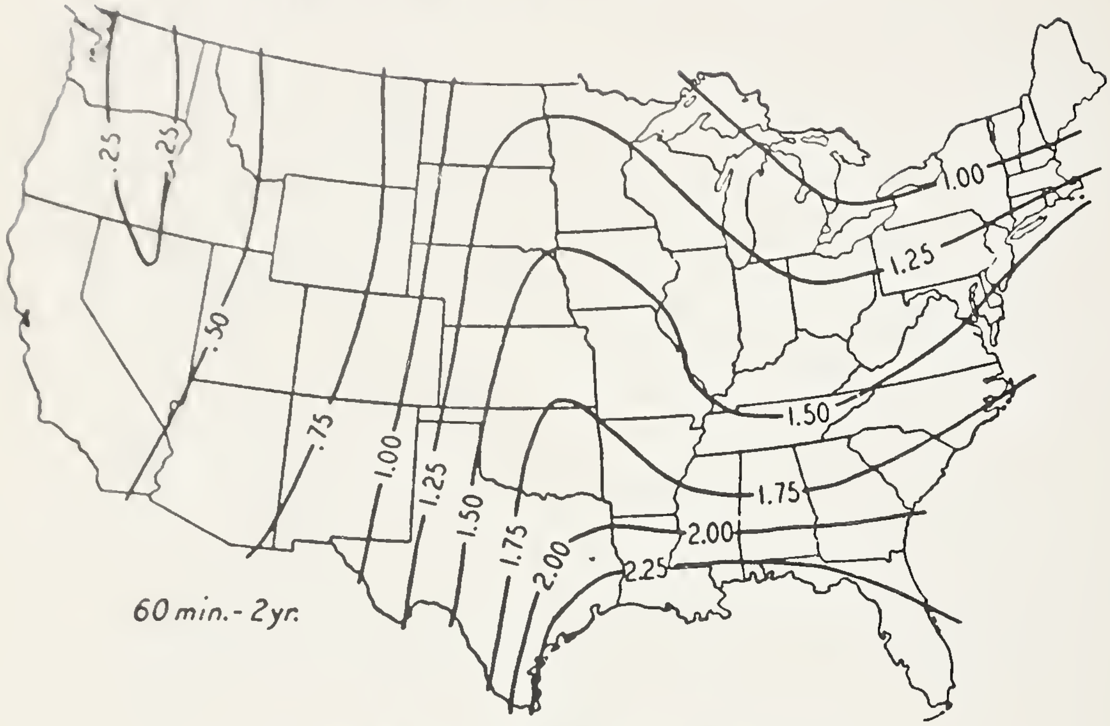


FIGURE 38.—One-hour rainfall, in inches, to be expected once in 2 years.

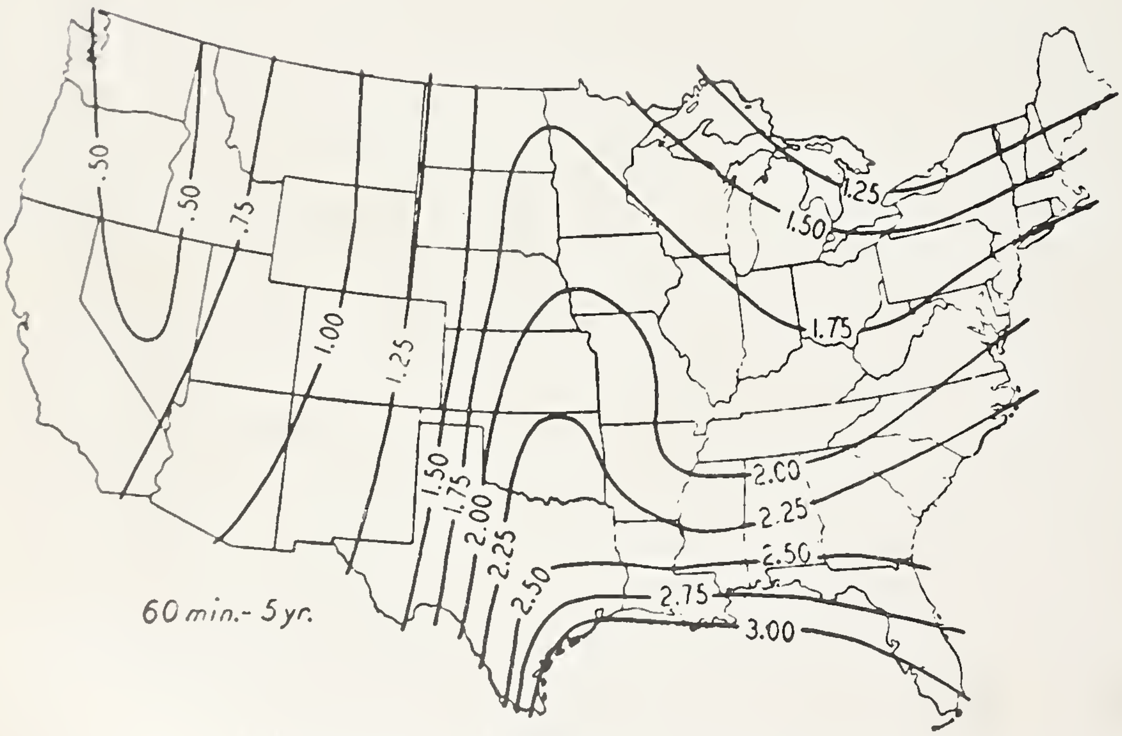


FIGURE 39.—One-hour rainfall, in inches, to be expected once in 5 years.

[Taken from Misc. Pub. No. 204, U. S. Dept. of Agriculture]

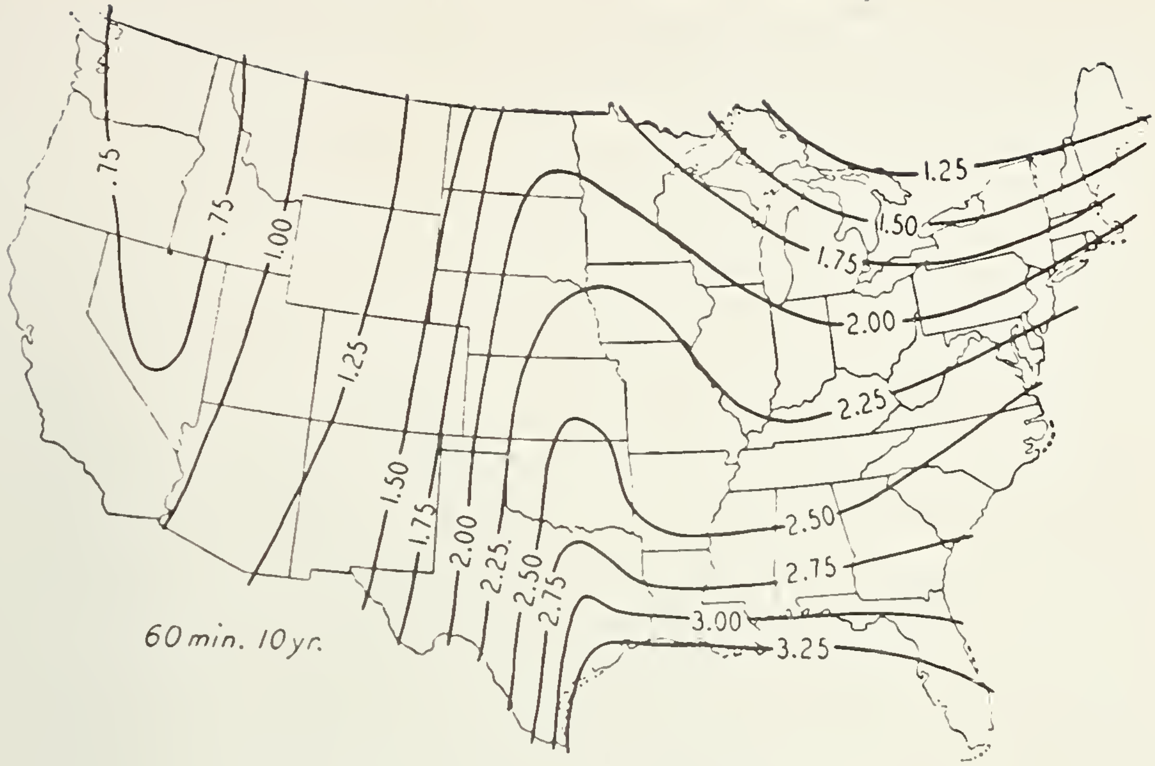


FIGURE 40.—One-hour rainfall, in inches, to be expected once in 10 years.

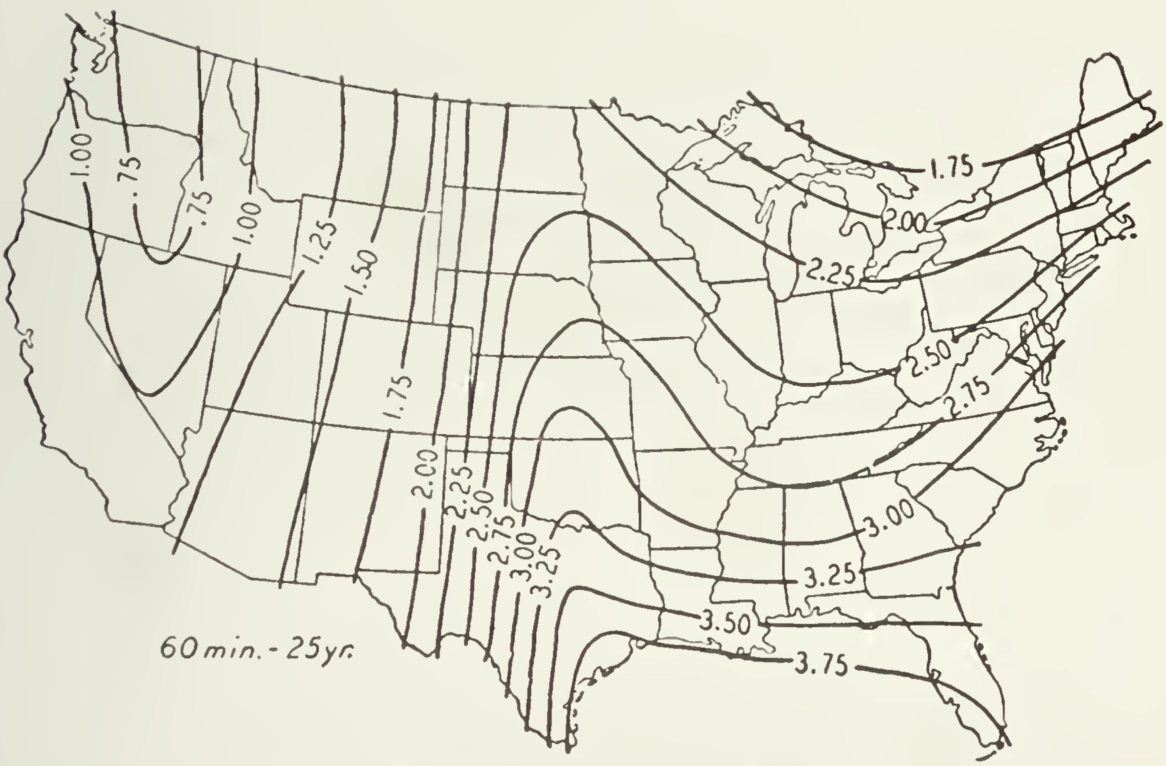
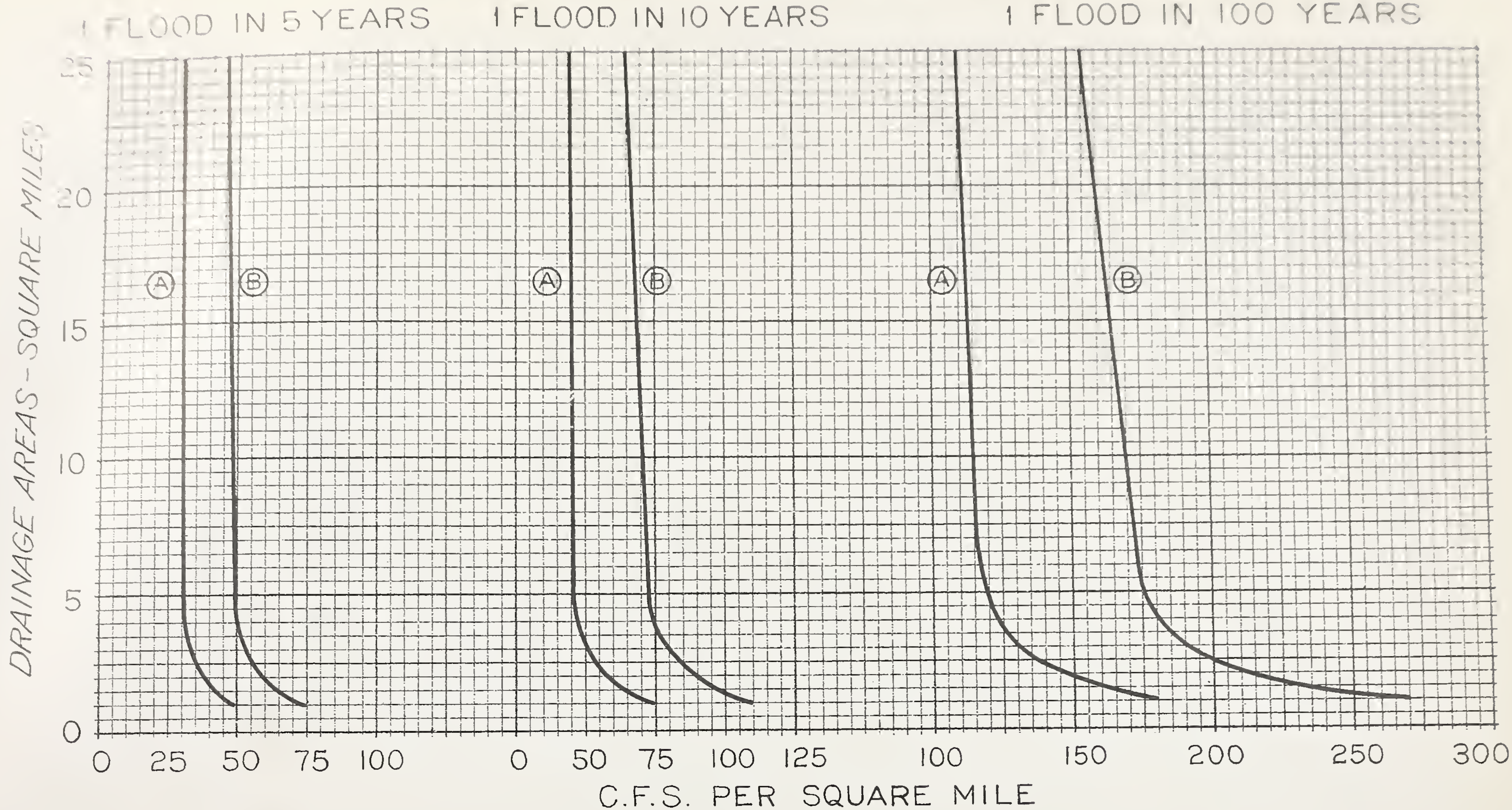


FIGURE 41.—One-hour rainfall, in inches, to be expected once in 25 years.

FIGURE 42– FLOOD FREQUENCY CURVES



CURVE (A) ALL MODOC AND EAST SLOPE OF PLUMAS, TAHOE, ELDORADO AND LASSEN FORESTS

CURVE (B) WEST SLOPE OF PLUMAS, TAHOE, ELDORADO AND LASSEN FORESTS

The run-off factor, C, will vary with the type of vegetation and soil. For western range conditions, values of 0.4, 0.6, and 0.9, respectively, are recommended for brushed or timbered areas, sod-covered areas, and barren or cultivated land. These values are for short intense rainfalls where the accumulation on the ground is too great to allow much percolation or absorption, and are not applicable to the more casual rains.

The greatest flow at the outlet to a watershed will occur when the entire area is contributing run-off, which does not happen until rain has been falling long enough to allow run-off from the most remote corners to reach the outlet. This interval is known as the time of concentration. Since the highest rainfall intensities are of short duration, the value of I to be used is the equivalent rate per hour of the maximum fall expected in an interval equal to the concentration period. For example, assume the longest path of flow from the most remote part of the watershed to the outlet is 3,600 feet, and the ground slopes indicate that the velocity of flow will average about 4 feet per second. It will take 3,600/4, or 900 seconds, which is 15 minutes for the flow to concentrate at the outlet. In central Wyoming, the 15-minute rainfall to be expected once in 10 years is 0.75 inch, or $I=\frac{60}{15}\times 0.75=3.0$ inches per hour.

To complete the example, it will be assumed that the watershed area of 180 acres is made up of 40 acres of barren ground, 50 acres of brush and trees, and 90 acres of well-sodded ground.

$$Q=(0.9\times 3\times 40)+(0.4\times 3\times 50)+(0.6\times 3\times 90)=330 \text{ cubic feet per second.}$$

The conditions in California in regard to run-off are quite variable, but have been favored with more abundant records and considerable study. Page 42 gives flood frequencies and amount for different sections of the national forests of that State.

16. Erosive Power of Water.

The source of trouble in our erosion problems is the unchecked passage of run-off over exposed soil surfaces at velocities which are high enough to permit transportation of soil particles from the terrain to the gullies, and from the gullies to the rivers where it passes beyond recovery. The methods of reducing the velocity and volume of the run-off have been discussed in the previous chapter. However, some idea of the erosive power of flowing water may give a better idea of the forces that are to be controlled to prevent damage.

The erosive power is the ability to dislodge soil from rest in its natural state, and the carrying power is the ability to carry it along after it becomes dislodged. The exact laws governing these two operations are not fully agreed upon, but in general, the erosive power of moving water varies with the square of the velocity and the carrying power varies approximately with the sixth power of the velocity. In other words, if the velocity is doubled, the erosive power is multiplied by 4 and the carrying power by 64. On steep slopes the carrying power is aided by the natural tendency of the larger stones to roll down hill and to grind and cut a deeper channel as they go.

In table III on page 44 is given the opinion of one authority on safe water velocities for the common materials. Table IV gives values at which these materials will be carried along in smooth-flowing channels of uniform section. In gullies and on hillsides where the channels are irregular and the flow is turbulent, the carrying power is probably greater.

In seeking to bring about deposition of the silt load, it will ordinarily be necessary to reduce the velocity below the values shown in table IV.

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Table III.—*Permissible canal velocities after aging*

[Recommended in 1926 by Spec. Comm. on Irr. Research, A. S. C. E.]

Original material excavated	Velocity
	Feet per second
Fine sand, noncolloidal	1. 5
Sandy loam, noncolloidal	1. 75
Silt loam, noncolloidal	2. 0
Alluvial silts, noncolloidal	2. 0
Ordinary firm loam	2. 5
Volcanic ash	2. 5
Fine gravel	2. 5
Stiff clay, very colloidal	3. 75
Alluvial silts, colloidal	3. 75
Graded, silt to cobbles, colloidal	4. 0
Coarse gravel, noncolloidal	4. 0
Shales and hardpans	6. 0

Note.—The term "colloidal" is assumed to be the same as cohesive in this application.

Table IV.—*Water velocities required to carry various materials*

Velocity in feet per second	Material
0. 25	Fine clay.
. 5	Fine sand.
. 67	Sand coarse as linseed.
1. 0	Sweep along fine gravel.
2. 0	Roll along pebbles up to 1 inch diameter.
3. 0	Sweep along slippery angular egg-size stones.

17. Capacity of Ditches and Channels.

The size of diverting ditches depends of course upon the amount of run-off to be expected from the area above them. Having found the rate of run-off, the ditch is designed to have a capacity of the same amount, allowing a margin of safety against overflowing the banks after they have settled. When the downhill side of a ditch is all or part in fresh fill, an allowance of about 20 percent of the filled height should be added for settlement and compaction.

The amount of water that a ditch will carry depends on the cross-section area, the slope of the trench bottom, the hydraulic radius (ratio of the area to the wetted perimeter), and the roughness of the material which forms the sides and bottom. None of the accepted formulae for carrying capacity is very simple, but the Manning formula is as satisfactory as any, and will be explained here.

Since we already know the amount of run-off, the problem is to determine the size and proportions of the ditch to carry it off without serious erosion of the bank material. From table III above pick the velocity that will be safe for the soil to be encountered. Remember that loose soil offers little resistance to erosion, so if parts of the ditch go through newly placed fill, these parts should be tamped to prevent loss.

The Manning formula for the velocity in an open channel is:

$$V=\frac{1.486}{n}R^{2/3}\,s^{1/2}$$

in which V = the average velocity in feet per second

n = the roughness coefficient

R = the hydraulic radius, or the cross-section area of the water divided by the wetted perimeter

s = the channel slope, or the $\frac{\text{vertical drop}}{\text{distance}}$

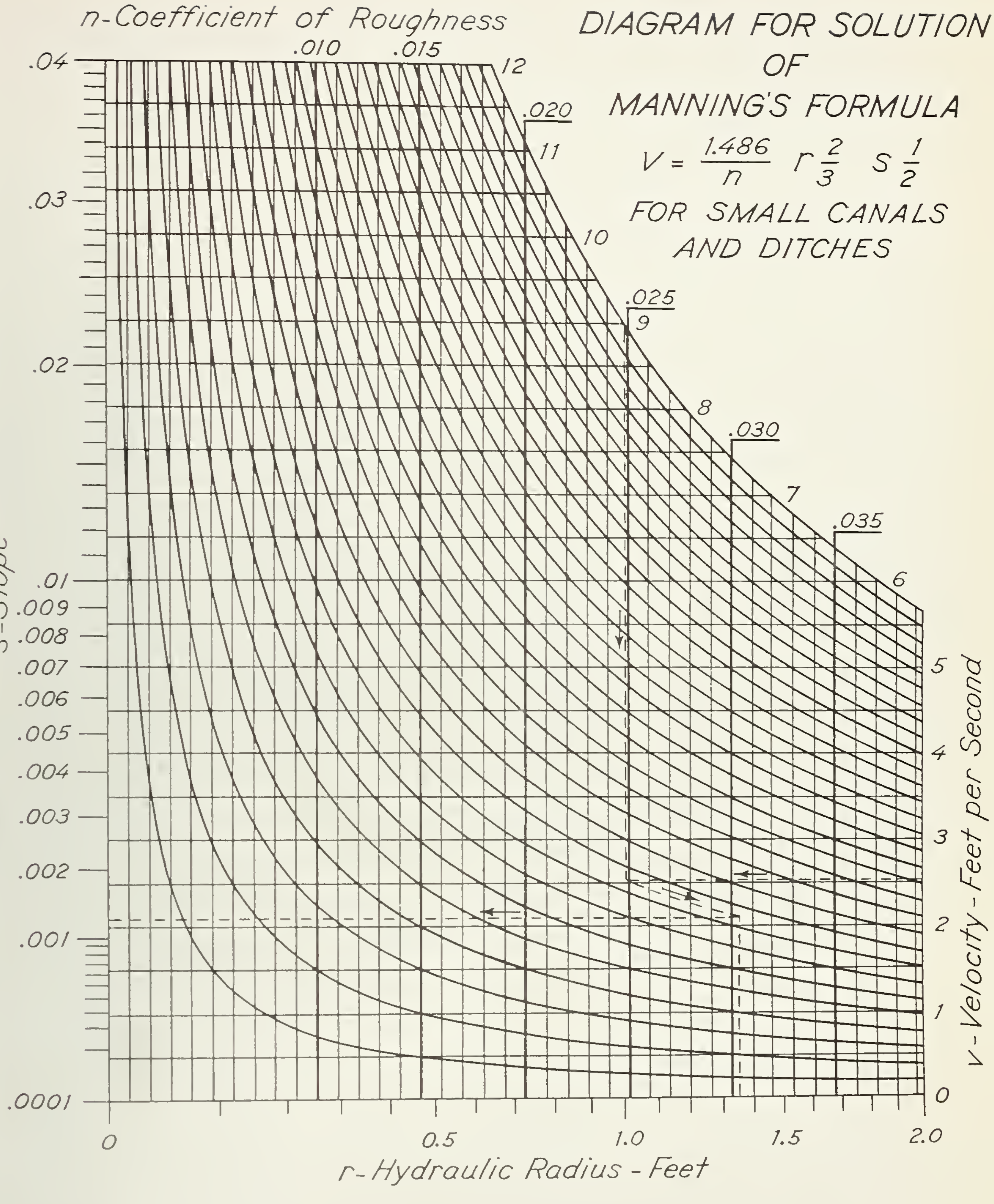
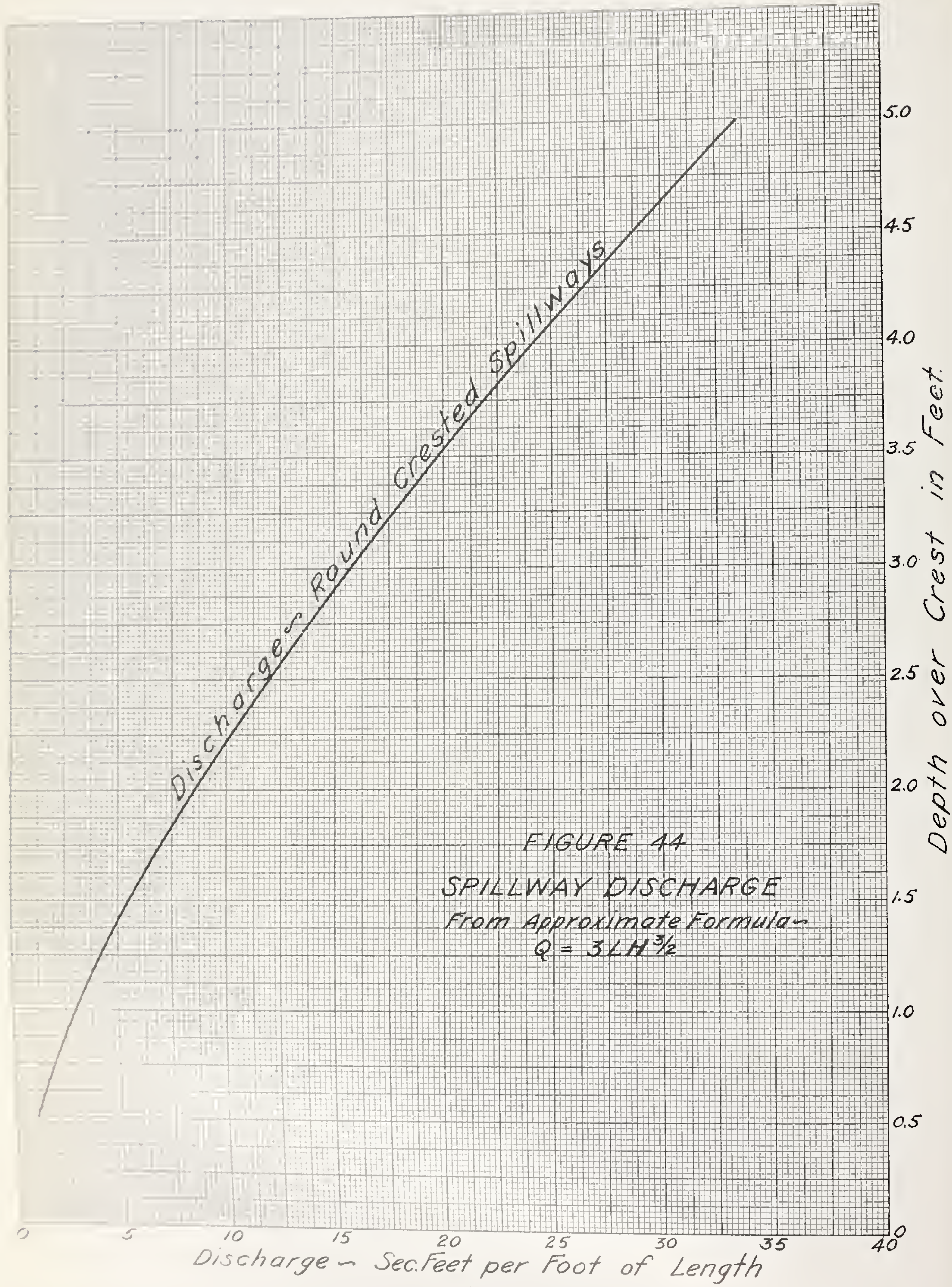


DIAGRAM FOR SOLUTION OF MANNING'S FORMULA
$V = \frac{1.486}{n} r^{\frac{2}{3}} S^{\frac{1}{2}}$
FOR SMALL CANALS AND DITCHES
n-Coefficient of Roughness
.010
.015
.020
.025
.030
.035
12
11
10
9
8
7
6
s-Slope
.04
.03
.02
.01
.009
.008
.007
.006
.005
.004
.003
.002
.001
.0001
v-Velocity-Feet per Second
5
4
3
2
1
0
0
0.5
1.0
1.5
2.0
r-Hydraulic Radius-Feet

FIGURE 43


Discharge ~ Round Crested Spillways
FIGURE 44
SPILLWAY DISCHARGE
From Approximate Formula ~
Q = 3LH 3/2
0
5
10
15
20
25
30
35
40
Discharge ~ Sec. Feet per Foot of Length
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Depth over Crest in Feet

In ditches with earth bottom and slopes, the value of n will range from 0.02 when the ditch is new and trimmed carefully to smooth surfaces, to 0.03 after it has been in use for a long time and has been roughened and obstructed by weeds. For the average condition, use 0.025. Having determined n and V, turn to figure 43 on page 45. Find the value n at the top, and follow vertically downward to intersection with the horizontal line from the V scale at the right. From this intersection, follow in the direction of the curved lines until vertically over the assumed value of R, and then horizontally to the scale at the extreme left which gives the slope s.

It will be seen that there is a wide range available for the choice of the hydraulic radius, R, and that as the value increases, the slope needed to maintain the desired velocity grows smaller.

It will be up to the field engineer to determine what base width and side slopes are best for the local conditions, and lay out his ditch section accordingly. He can then determine what depth will give the required area, and can compute the hydraulic radius of the section.

As an example, assume that we want to find the size and slope of a ditch to carry 40 cubic feet per second through ordinary firm loam. The maximum safe velocity from table III is 2.5 feet per second, and the cross-section area is therefore $40/2.5=16$ square feet. Side slopes in this material will probably be stable on a 1½ to 1 slope, so we assume a bottom width of 3 feet, draw a section to a convenient scale, and by cutting and trying find that with a water depth of 2.4 feet, the area is 15.96 square feet and the hydraulic radius is $15.96/11.8=1.35$. Next on page 45 we enter the diagram top under $n=0.025$, and drop down opposite $V=2.5$. From this intersection, follow the direction of the curved lines until vertically above the value $R=1.35$. Horizontally opposite this point, it is found that a slope, s, of 0.0012 is required, or a drop of 0.12 feet per hundred feet of ditch.

18. Capacity of Overflow Spillways and Channels.

A high degree of accuracy is not necessary in figuring the discharge capacity of the overflow crests of erosion structures. The usual formula for this work is $Q=CLH^{3/2}$, where C is a coefficient which depends upon the shape of the overflow crest, L is the length of the section that the water flows over, and H is the difference in elevation between the water in the pool above the dam and the top of the overflow crest. For the ordinary rock or brush structure the value of C is set at 3.

The curve on page 46 gives the amount of water that will flow over each foot of crest for heads up to 5 feet. Multiply these values by the length of the crest to get the total discharge.

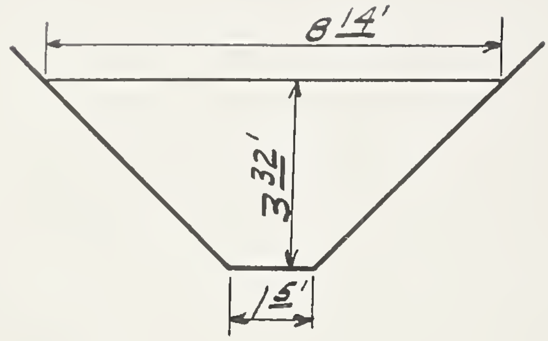
For larger dams of the soil-saving variety with drop inlet spillways, the capacity of the drop inlet is treated in section 19.

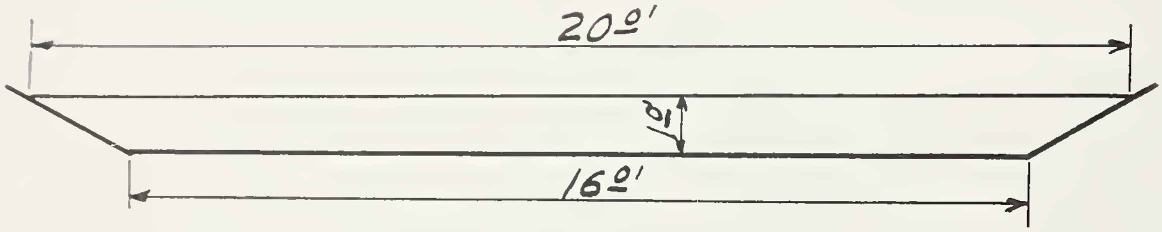
Every drop inlet spillway should be supplemented by an overflow channel designed to carry the excess flow up to a hundred-year frequency to secure a reasonable factor of safety against failure. Because of its infrequent use, the so-called broad-crested spillway consisting of a sodded but unpaved channel through the natural bank material will serve the purpose in most soils, but should be limited to drainage areas of 1 square mile maximum.

The capacity of these channels is figured in the same manner as outlined in section 17. A heavy sod cover should be established on the new channel as soon as possible after it is completed, and a value of n to cover this condition must be used. For heavy sod surfaces with a fair growth of grass, use $n=0.035$. Safe velocities under these conditions will run as high as 6 feet per second with 4 or 5 feet per second advisable if the cover is thin.

In designing the channel, a wide shallow section will give the least trouble from erosion. As an illustration, a wide shallow channel will pass the same flow at a lower velocity than a deep and narrow channel, if the slope of both channels is the same.

$n=0.035$	$R=1.46$
$A=16.0$	$Q=90$ cubic feet per second
$v=5.62$	$s=0.0105$





$n=0.035$	$R=0.88$	$s=0.0105$
$v=4.0$	$A=18$ square feet	$Q=90$ cubic feet per second

Comparisons of velocities in deep and shallow channels.

The two channel sections above have the same capacity, and the slope is the same for both channels. The deep channel will flow with a velocity of 5.62 feet per second, while the wide, shallow channel will have a velocity of only 4 feet per second. This illustrates the principle to be followed in the design of broad-crested spillways, that with channels of equal capacity, the wide, shallow channel will have the least tendency to erode.

19. Capacity of Drop Inlet Spillways.

Tables giving the discharge capacity of drop inlet spillways made of culvert pipe and of concrete are shown on pages 72 and 73, respectively.

These tables were computed from the pipe discharge formula

$$Q=A\sqrt{\frac{2gH}{K}}$$

where, Q = discharge in cubic feet per second

A = area in square feet

g = 32.2 feet per second

H = effective head in feet

$K = 1+(ke+f\frac{L}{D}+kb)$ (the friction losses)

ke = the entrance loss

$f\frac{L}{D}$ = the losses in the straight run

kb = the elbow loss

The coefficients for the losses at the entrance and at the elbow were taken from University of Wisconsin Bulletin No. 80, by L. H. Kessler, giving the results of recent laboratory tests.

Spillways of this type reach a practical maximum capacity when the depth of water over the lip is 1.2 times the width of the opening. Further increase in the head results in only a slight additional flow.

It is recommended that in the design of these spillways, capacity be provided to pass the 25-year floods. To prevent damage from greater floods, an auxiliary overflow channel should be provided with enough additional capacity to provide whatever factor of safety is warranted by the value of the structure. Usually these dams are so small that any damage that they would cause by failure is not serious, but this matter should be checked carefully during the design stage.

The capacity of open channel overflow spillways has been treated in section 18, page 47.

Chapter IV

GULLY STRUCTURES

20. Use of Gully Structures.

Gully-head plugs (measure k) are structures designed to halt the upstream progress of gullies by reducing the grade at the drop to a slope which, when paved or protected, will allow the drainage to get from the upper to the lower level without further erosion.

Check dams can be used to prevent further cutting of the gullies (measure j) or as soil-saving dams to cause the gullies to fill up (measure l).

Gully-head plugs and check dams can be made from various materials including brush, logs, wire, corrugated galvanized sheet metal, rocks, masonry, and concrete or combinations of them. The material selected should be that which will give a satisfactory structure at the least total cost for labor, materials, and maintenance during its necessary life.

Gully checks constructed of wire fencing should not be more than 18 inches high.

Loose rock, rock and wire mattress, or brush checks should not be constructed higher than 18 inches.

Structures of logs or lumber, where their probable length of life is sufficient, can be constructed to heights greater than 18 inches but should be provided with adequate aprons below and cut-off walls at the abutments.

Structures of concrete, rubble masonry, and loose rock faced with rubble masonry can be constructed to almost any height that would be necessary for controlling erosion in gullies. It is important that they be provided with cut-off walls at the abutments and aprons below to prevent end and under cutting.

21. Rock Gully-Head Plug.

Rock should be used in the construction of the gully plugs, if available. It is considered superior to brush for the purpose, due to greater ease and permanency of construction.

The first step in the construction of the gully plug is to round back the overfall to a fairly flat slope, upon which the plug can be constructed. The rock should be carefully selected and laid, so that the rocks are properly keyed together. To prevent washing out care should be taken to pack the interstices between the rocks tightly with gravel or small broken rock, and litter, particularly at the crest, where it joins the level of the meadow. The plug should be constructed slightly low in the center, but not too much so, so that the water running from the natural watercourse on the meadow will enter the gully at the proper place. The sides should be raised slightly above the level of the meadow and extend a few feet back onto this level, so that drainage will be directed over the gully plug and not around the sides.

See figure 45 for construction details.

22. Brush Gully-Head Plug.

Brush can be used in the construction of a gully-head plug if no rock is readily available. It is applicable to advancing overfalls of any height, as in the case of a rock structure. It should be accompanied also with a check a few feet below.

First, the overfall should be properly trimmed back to a flat, even slope. The next step is to place a fine layer of litter or very fine brush, to be covered with alternate layers of coarser brush properly compacted. The whole should be staked and wired down tightly to prevent the water from eroding the gully bottom below the brush. Attention should be given to the same points as mentioned in connection with the rock type of gully plug. If properly constructed it will withstand a very heavy run-off without being disrupted.

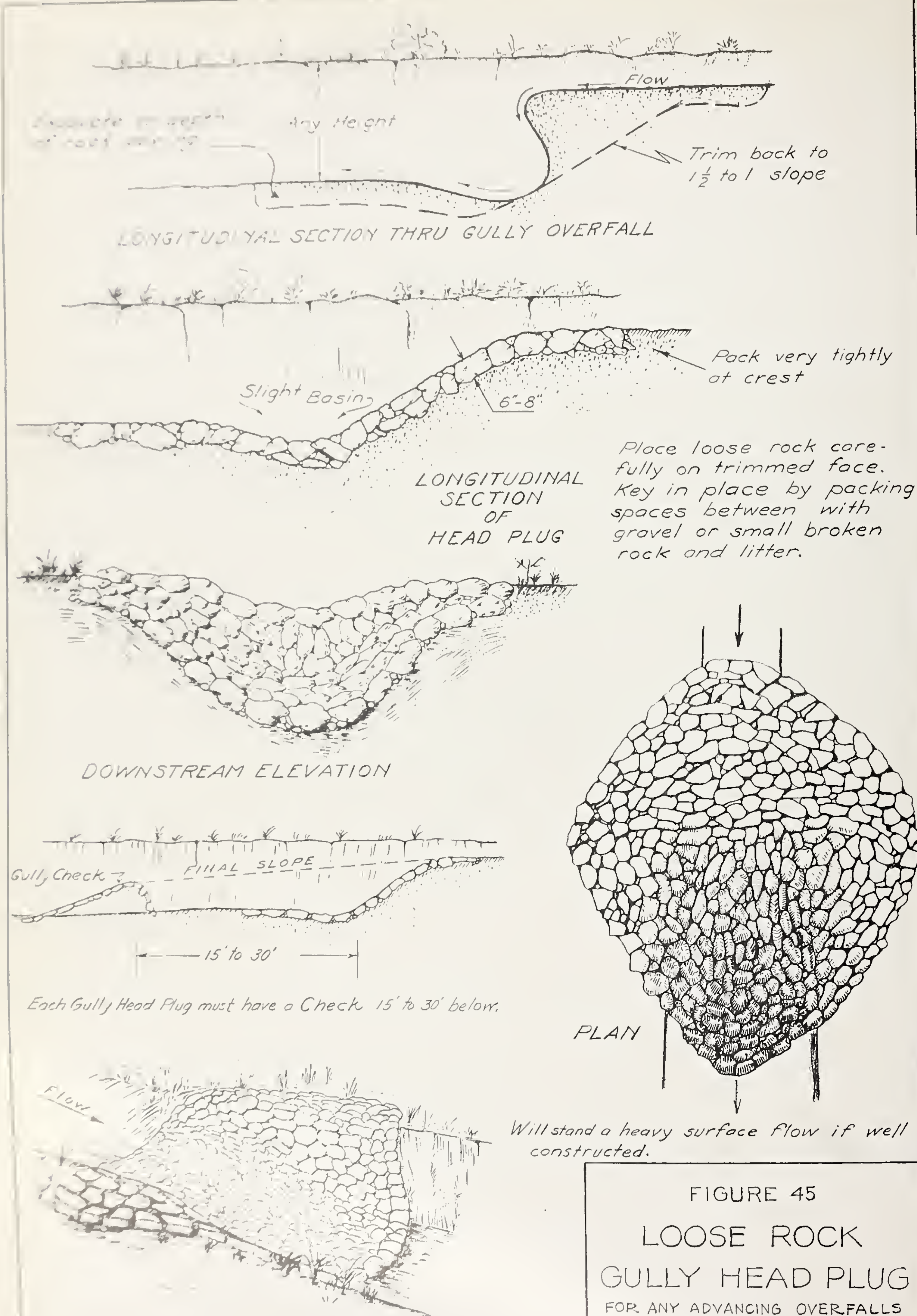


FIGURE 45
LOOSE ROCK
GULLY HEAD PLUG
FOR ANY ADVANCING OVERFALLS

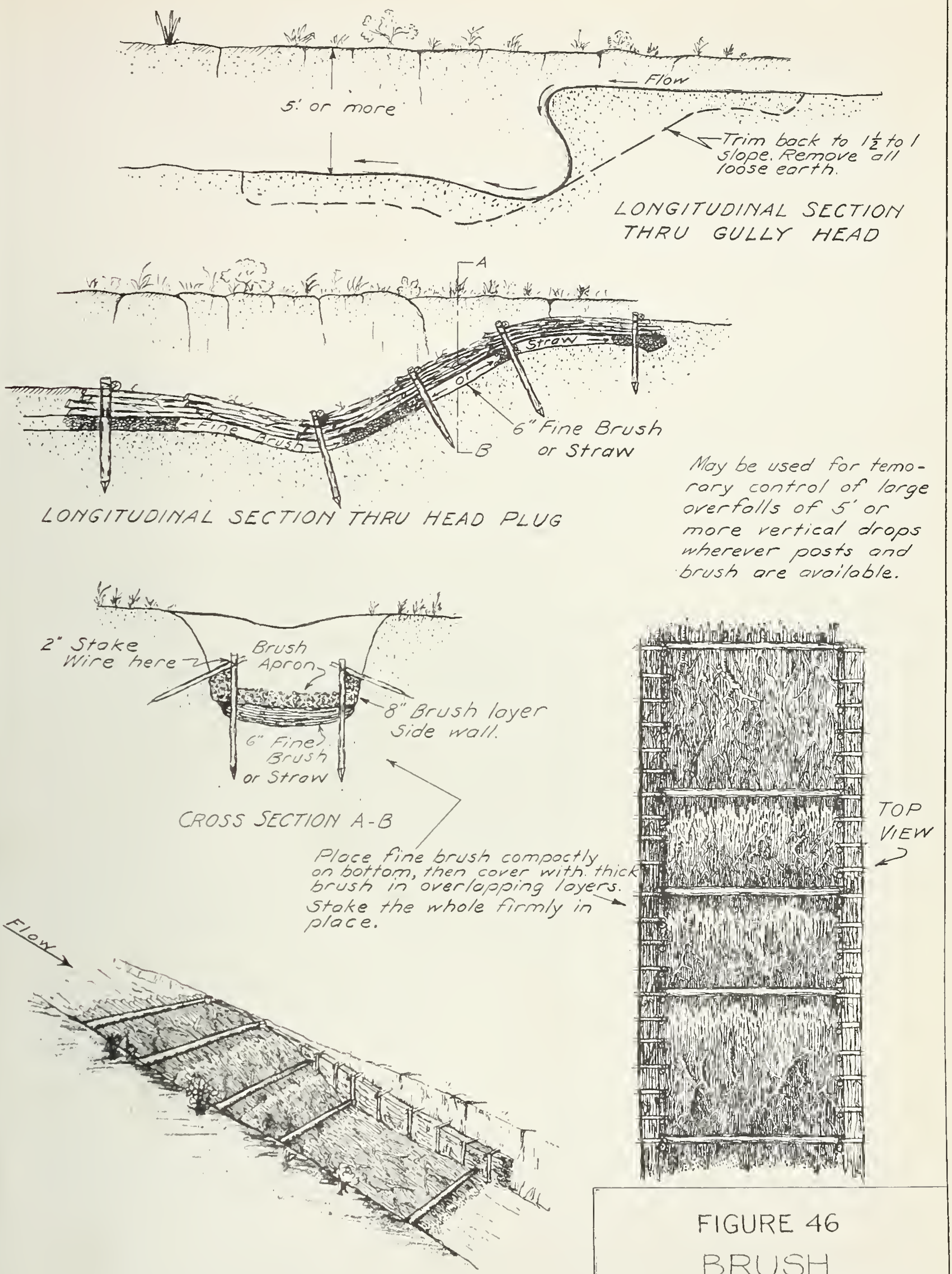


FIGURE 46
BRUSH
GULLY HEAD PLUG

Under all circumstances, this brush construction should be considered temporary in nature, unless a heavy growth of vegetation returns to protect the slope. It may require maintenance, from year to year, dependent upon the kind of brush used and the conditions to which it is subjected.

See figure 46 for construction details.

23. Prefabricated Metal Gully-Head Plugs.

The corrugated iron manufacturers have developed sections of half-round conduit for use as flumes, etc. They also can furnish a wing-shaped inlet for diverting surface flow into the flume sections. Prefabricated sections of this kind may have application in some locations for passing run-off over gully heads where the required capacity is not too great.

24. Loose Rock Gully Checks.

The use of loose rock in gully checks is desirable if an adequate supply of rock is available. The rock is used with gravel or broken stone, and litter, depending on which is most easily secured. The initial construction should be limited to a height of 18 inches, since these structures cannot be regarded as permanent and no vegetation which may grow on the new soil could withstand an overfall of much more than this amount.

The first step in the construction of a loose-rock check is to round off the sides of the gully to an even slope, about 1:1, at the same time removing all loose material on the bottom. This is followed by the construction of a cut-off trench. After this preparation of the site the rocks composing the structure should be placed, keying them together as tightly as possible, and filling the interstices with gravel or small broken stone and litter. Care should be taken to see that the crest of the structure is made as level as possible, and that the wings are extended well up over the edge of the gully. Attention must be given also to the construction of the apron in extending the sides well up above the probable high-water line, so as to prevent scouring of the gully sides. Logs located at each end of the structure on the meadow level will prevent cattle from walking too close to and breaking down the ends of this structure. Finally the upstream slope must be backfilled with soil to make the barrier watertight.

In working out the proportions of the barriers the need of an adequate waterway to carry the high-water flow should not be overlooked. If possible, a freeboard of 6 inches between the high-water line and top of the bank should be provided. The capacity required should be determined in accordance with the principles outlined in the pages dealing with run-off. A well-built structure of this type is capable of resisting a flow up to about 18 inches of depth without serious disturbance.

See figure 47 for construction details.

25. Loose-Rock Checks With Facing Laid in Cement Mortar.

Loose-rock checks faced with stones laid in cement mortar where exposed to the current are comparable to concrete and rubble construction in permanency. They are adapted to locations where large quantities of rock of all kinds are readily available and where the flood flows are greater than loose-rock surfaces can withstand, or the structures are to be higher, thus subjecting their facing to higher velocities than is allowable for loose rock.

They may be located on an ordinary soil foundation without excessive excavation if an adequate cut-off wall and apron are provided. The stability is greatly enhanced over the all-loose-rock structure by laying the outside course of rock in cement mortar, covering the face of the check, the crest and ends of the spillway, and the apron below the check. A mix of 1 cement to 3 sand should be used in this work. The remainder of the check is composed of carefully placed loose rock. Proper care in the construction, particularly in extending ends and constructing the apron, must be exercised.

The spillway area should be determined as indicated in the accompanying run-off data. A good structure of this type will be able to withstand the most severe storms.

See figures 48 and 49 for construction details.

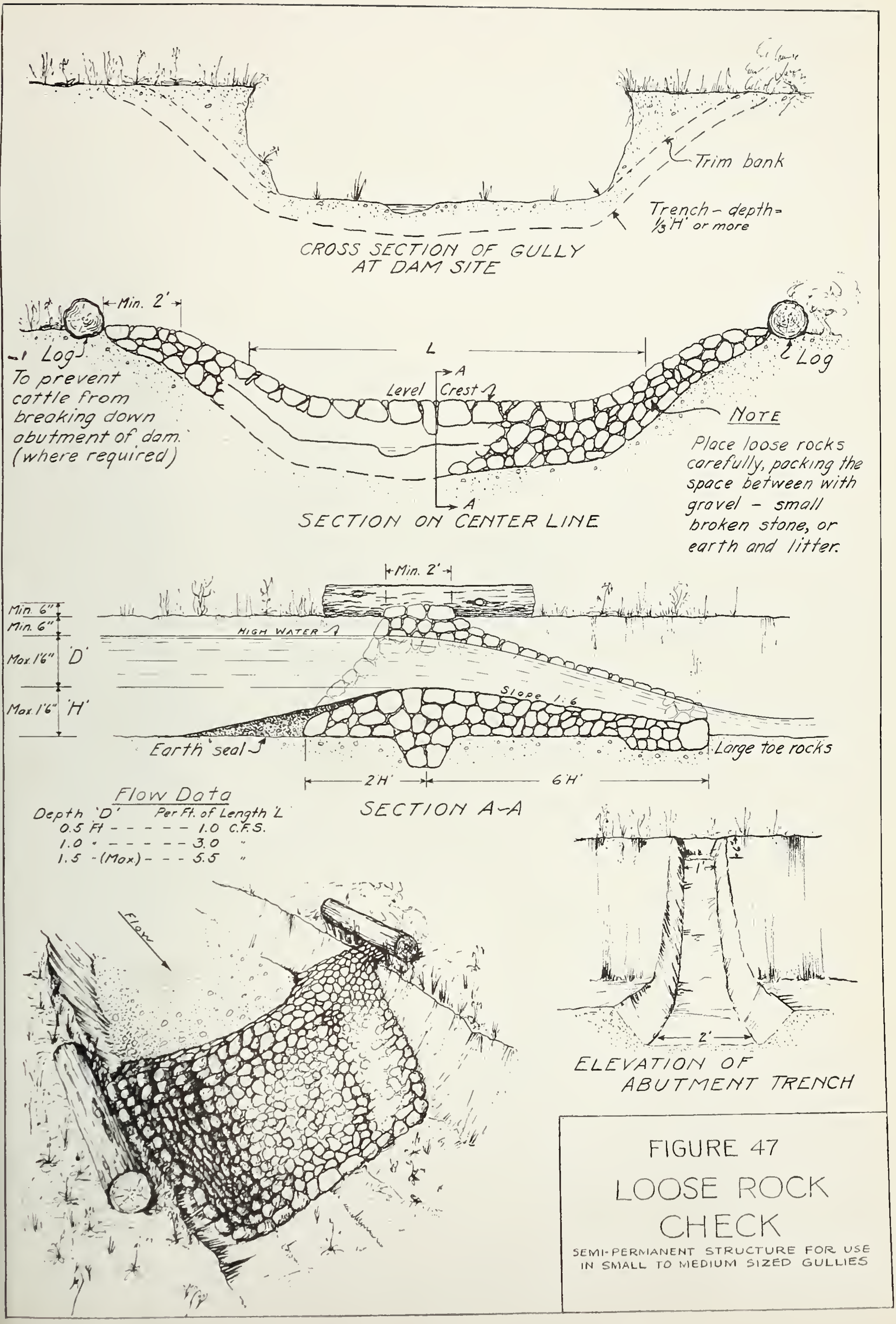
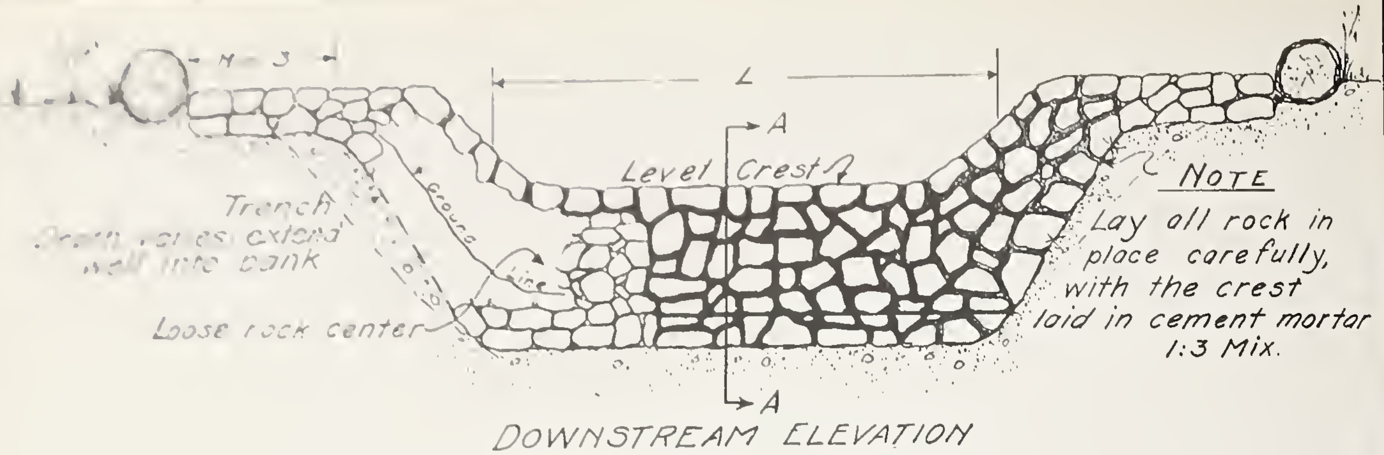
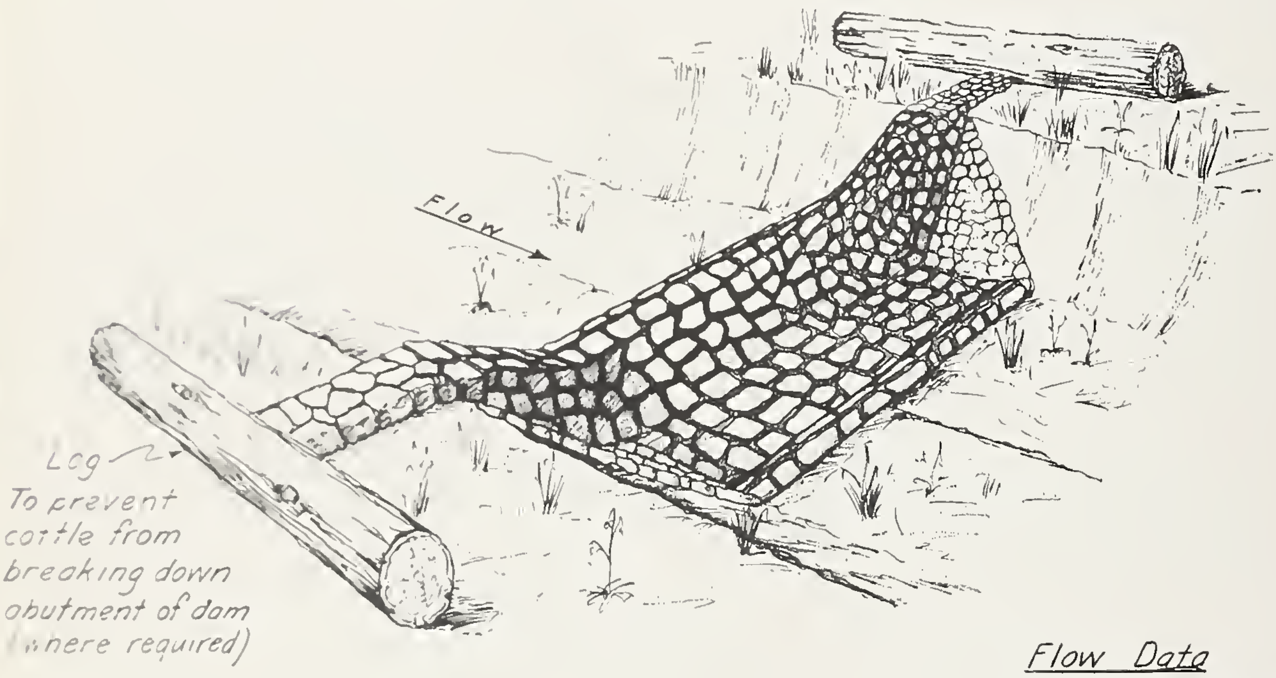


FIGURE 47
LOOSE ROCK CHECK
SEMI-PERMANENT STRUCTURE FOR USE IN SMALL TO MEDIUM SIZED GULLIES





Flow Data

Depth 'D'	Per Ft. of Length 'L'
0.5 Ft	1.0 C.F.S.
1.0 "	3.0 "
1.5" "	5.5 "
2.0 "	8.5 "
2.5 "	12.0 "

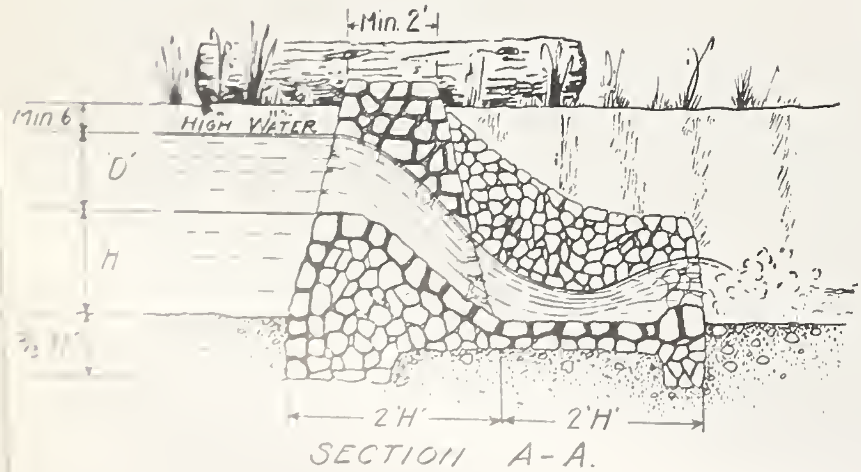


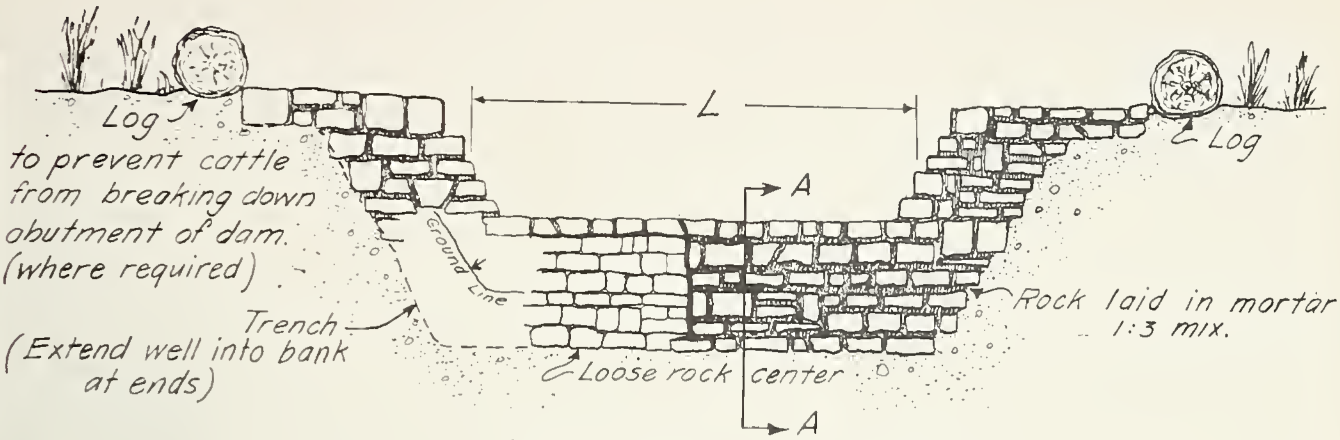
FIGURE 48

LOOSE ROCK CHECK

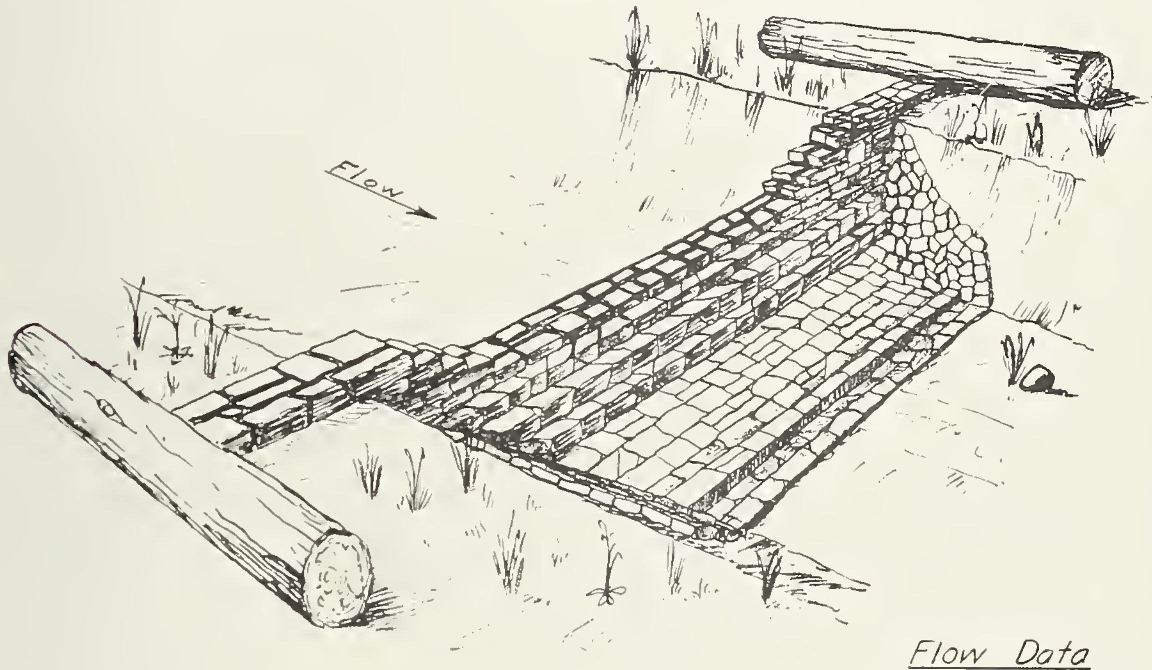
WITH

RUBBLE MASONRY FACING

PERMANENT STRUCTURE FOR CONTROL IN ANY GULLY

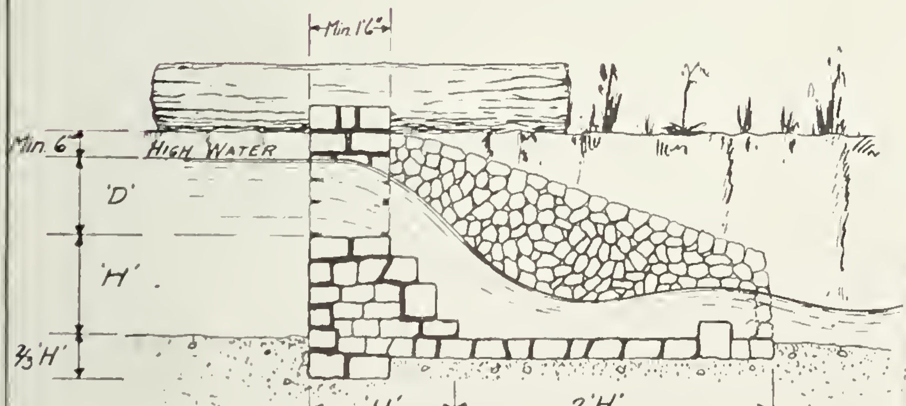


DOWNSTREAM ELEVATION



Flow Data

Depth 'D'	Per Ft. of Length 'L'
0.5 Ft.	1.0 C.F.S
1.0 "	3.0 "
1.5 "	5.5 "
2.0 "	8.5 "
2.5 "	12.0 "



SECTION A-A

FIGURE 49

LOOSE FLAT ROCK DAM WITH RUBBLE MASONRY FACING

PERMANENT STRUCTURE FOR CONTROL IN ANY GULLY

26. Rubble-Masonry Checks.

The use of rubble masonry in the construction of a check instead of loose-rock construction may be advisable if there is difficulty in obtaining good rock in quantity and if cement and sand are readily available.

After the usual slope trimming, removing of loose material, and trenching, the rock may be placed. It should be carefully laid in cement mortar, using a mix in the proportion of 1 cement to 3 sand. Care should be taken in this type of construction to see that all materials are reasonably clean.

Attention should be given to such items of construction as properly extending the ends of the structure up and over the banks, protection of the banks and gully floor below by the apron, placing of the protecting log, etc. Adequate spillway area must be provided, allowing a minimum of 6-inch freeboard between high water and the meadow level. This type of structure should be considered as first-class construction and of a distinctly permanent nature.

See figure 50 for construction details.

27. Concrete Checks.

Concrete construction will be used only where the most permanent type of control is required and where sufficient rocks of sizes over 10 inches for construction of rubble-masonry checks cannot be had. Necessarily, cement and good aggregate must be available.

The first step in the construction is to excavate to solid bearing, providing the necessary cut-off wall, and extending the excavation into the banks for the wing walls. Next, the structure must be formed up to receive the concrete. Unless it is over 5 feet in total height, a single pour can be used. The concrete mix should be in the proportions of 1 cement to 2½ sand to 5 coarse aggregate. Care must be taken to see that the materials are clean.

In designing the structure there should be sufficient spillway area for an estimated 10-year maximum run-off. This should be determined in the manner outlined in the accompanying run-off data.

See figure 51 for construction details.

28. Wire Fence Checks.

Wire fence checks are intended for use in raising the gully beds of silting channels. A series of these structures, across the bottom of the gully, located at intervals according to the slope, so that the crest of one is approximately on a level with the foot of the check above, will gradually raise the bed. The checks should be limited to a maximum height of 18 inches in order to insure their stability. The space behind these structures will probably silt up in one or two seasons. After the silt has been deposited on the maximum slope on which it will stand without the protection of vegetative cover, the next step will be to construct another series of similar checks on the deposited material. This process should be repeated until the stream bed is raised to the level required.

In the construction of barriers of this type, either old 1½- to 2½-inch pipe or 3- to 4-inch wood posts may be used, spaced at about 4-foot intervals across the gully or channel. A fairly close woven wire mesh, made of no. 9 wire, extending at least 1 foot below the surface of the gully bottom, should then be placed on the upstream side of the posts. The structure should be braced by tight wires extending upstream to stakes driven firmly into the ground. To provide against washout, the ends of the structure must be raised and projected into the bank, thereby keeping the water away from the ends. Finally, the earth and litter or tar-paper seal must be placed on the upstream side of the check to make it water-tight. A rock or timber apron should be provided to prevent undercutting of the downstream side.

The resulting structure should be considered as temporary in nature, and should not be placed in channels where the ordinary high-water flow will carry large amounts of abrasive material which might cut through the top strand, or where the volume and velocity of flow will be great enough to undermine the posts or ends. As a general guide to limit the volume and velocity of flow for earth or clay channels, the product obtained by multiplying the anticipated 10-year run-off in second-feet by the average slope

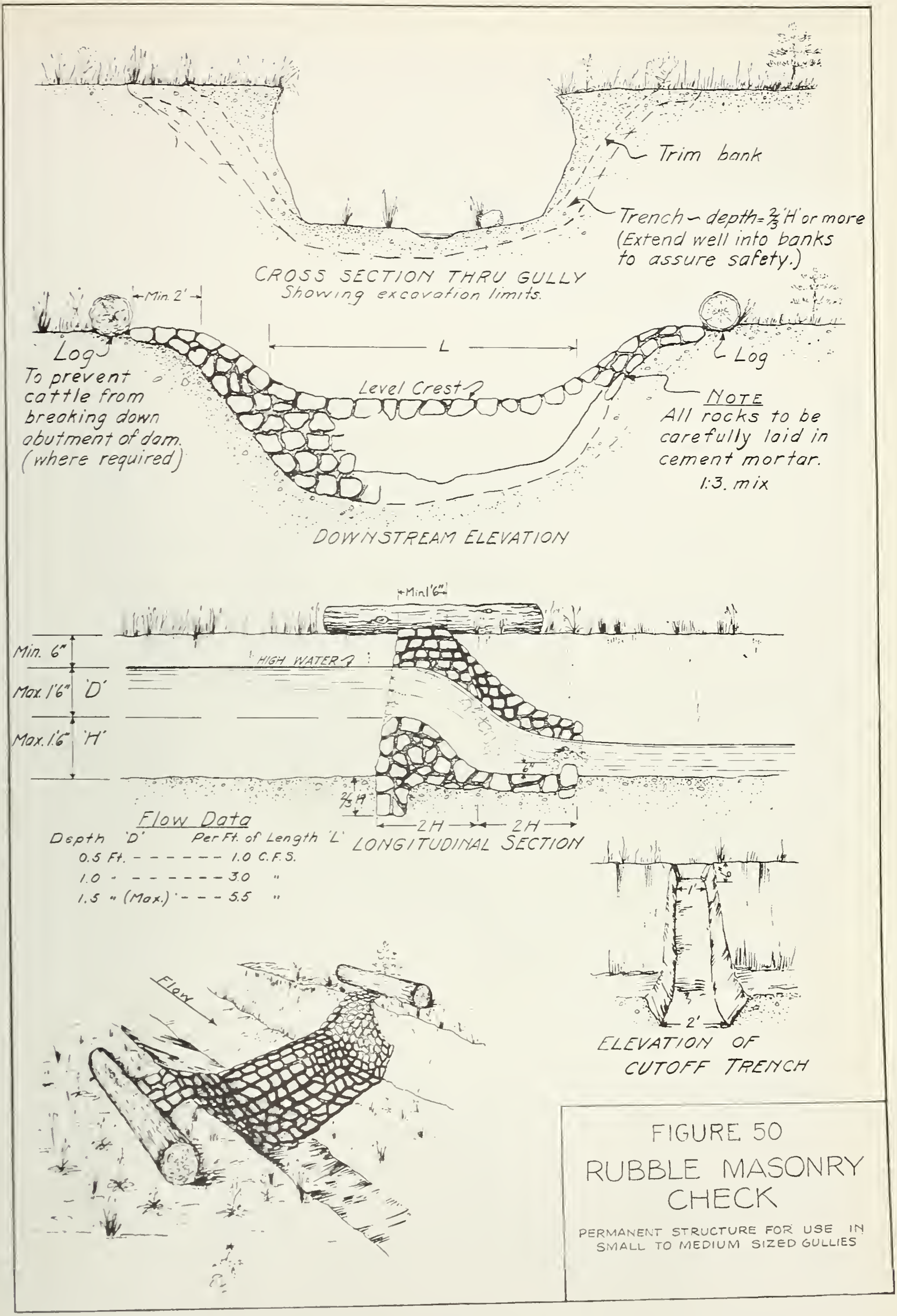


FIGURE 50
RUBBLE MASONRY CHECK
PERMANENT STRUCTURE FOR USE IN SMALL TO MEDIUM SIZED GULLIES

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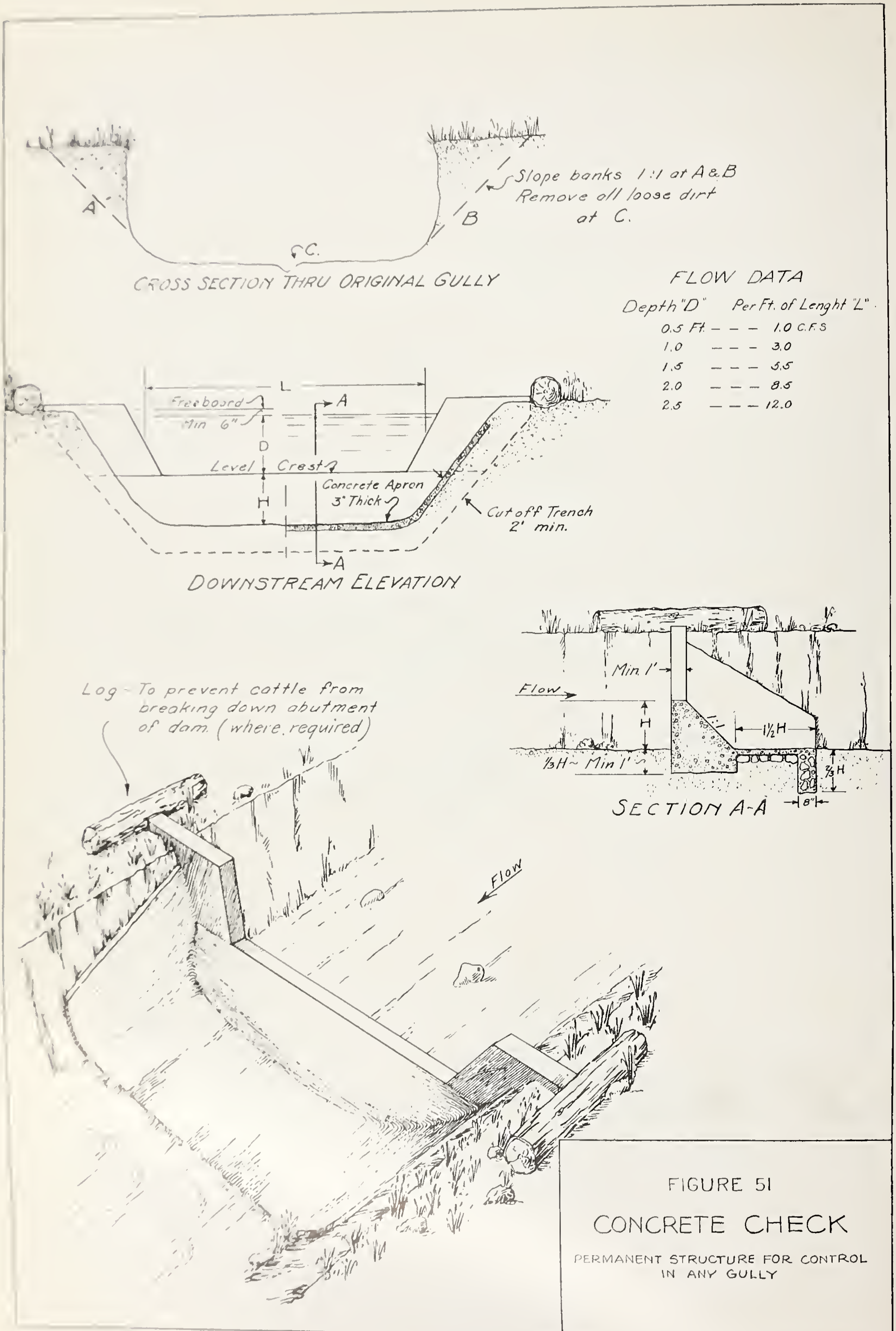


FIGURE 51

CONCRETE CHECK

PERMANENT STRUCTURE FOR CONTROL IN ANY GULLY

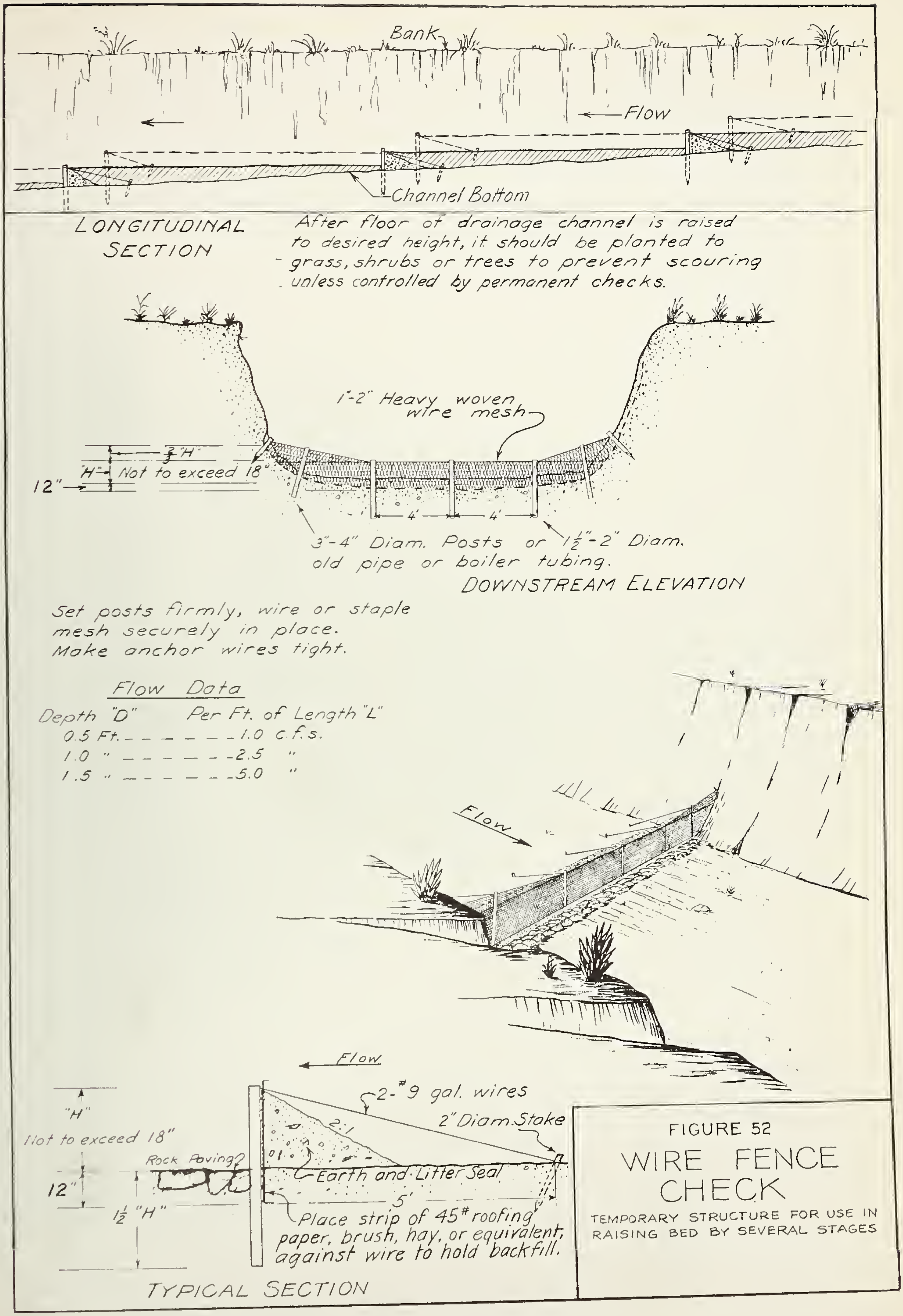


FIGURE 52
WIRE FENCE CHECK
TEMPORARY STRUCTURE FOR USE IN RAISING BED BY SEVERAL STAGES

of the channel in percent should not exceed 200. Thus, for a channel of 2 percent slope, this wire structure should not be used for flows greater than 100 second-feet.

See figure 52 for construction details.

29. Log Checks.

In certain areas where the meadows are surrounded by heavy timber, there may be very little rock available for construction purposes, which may necessitate the use of log checks. Checks built of logs may be considered of semipermanent nature only, as the life of such structures is limited by the durability of the logs used and will rarely exceed 10 years.

Ordinarily the height of log checks below the spillway notch to the gully bottom should be limited to a maximum of 2 feet.

The site for the structure must be trimmed and loose material removed. The excavation should be made just large enough to facilitate placing and tamping the logs. The vertical and wing logs must extend into solid ground a sufficient depth to guard against wash-out and provide stability for the structure. They should extend about 6 inches above the bank to provide the proper freeboard. In the construction of the apron, the sides must be built high enough to prevent side cutting. It is important to peel all logs and fit them tightly together. The backfill around the logs must be tamped into place so that firm ground remains around the completed structure. The logs may be spiked or wired together.

The waterway required should be computed according to the accompanying run-off data. A structure of this type will withstand very heavy storms, if it is in good condition.

See figure 53 for construction details.

30. Brush Checks.

The use of brush checks should be restricted to areas where large stones are scarce and small timber and plenty of brush are available for temporary construction. Very effective structures can be built if attention is given to details.

Dependent on the height required, the vertical posts, which give stability to the structure, may be driven into the ground or, if much over 2 feet high, can be placed in dug holes. Next to the ground between the two rows of posts, a compacted layer of fine brush is required. On top of this, layers of well compacted, coarser brush should be laid. The brush forming the apron should be held in place by a heavy log staked in position. To complete the check, crosspoles holding the brush down must be wired in place. Attention should be given to the item of making the ends of the structure higher than the center, and extending them 1 foot into the bank, in order to keep the water away from the ends of the dam, thus preventing wash-outs. Finally, the earth seal must be placed.

The spillway area should be determined according to the run-off data given.

Maintenance will be very necessary for this kind of dam.

See figure 54 for construction details.

A less substantial brush dam using a single row of posts can be used in places where the gully is small and the drainage area does not exceed 10 acres. Details are shown in figure 55.

The brush is most conveniently handled in bundles, and is usually wired in bundles of 6- to 10-inch diameter as it is cut. After excavating for the foundation, lay bundles for the apron, and then build up the check crest by tamping the bundles tightly and holding them in place by backfill on the upstream side. Since the posts furnish most of the strength, they must be of substantial size and solidly placed. Slope the crest as shown in the drawing to concentrate the flow toward the middle.

Still another form of brush treatment which is useful in shallow gullies, which have less than an acre of drainage area, is what is sometimes called "flow line brush paving." After shaping the gully to a crudely rounded invert shape, place a thick layer of brush with the stems normal to the direction of flow. Wire it in place by one or more longitudinal lines of wire that are fastened to stout stakes driven into the ground every few feet. Cedar or juniper brush are very desirable for this use.

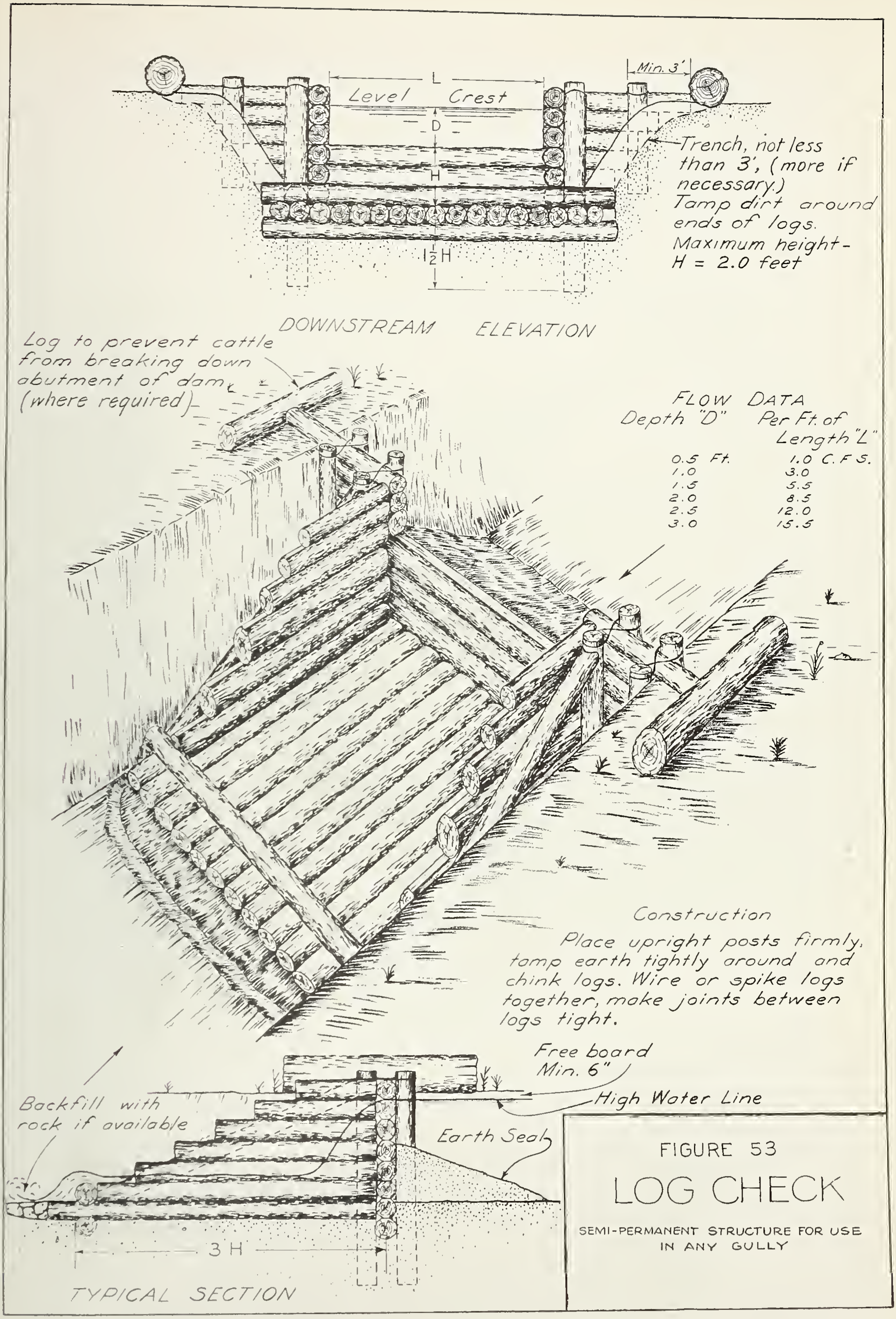


FIGURE 53

LOG CHECK

SEMI-PERMANENT STRUCTURE FOR USE IN ANY GULLY

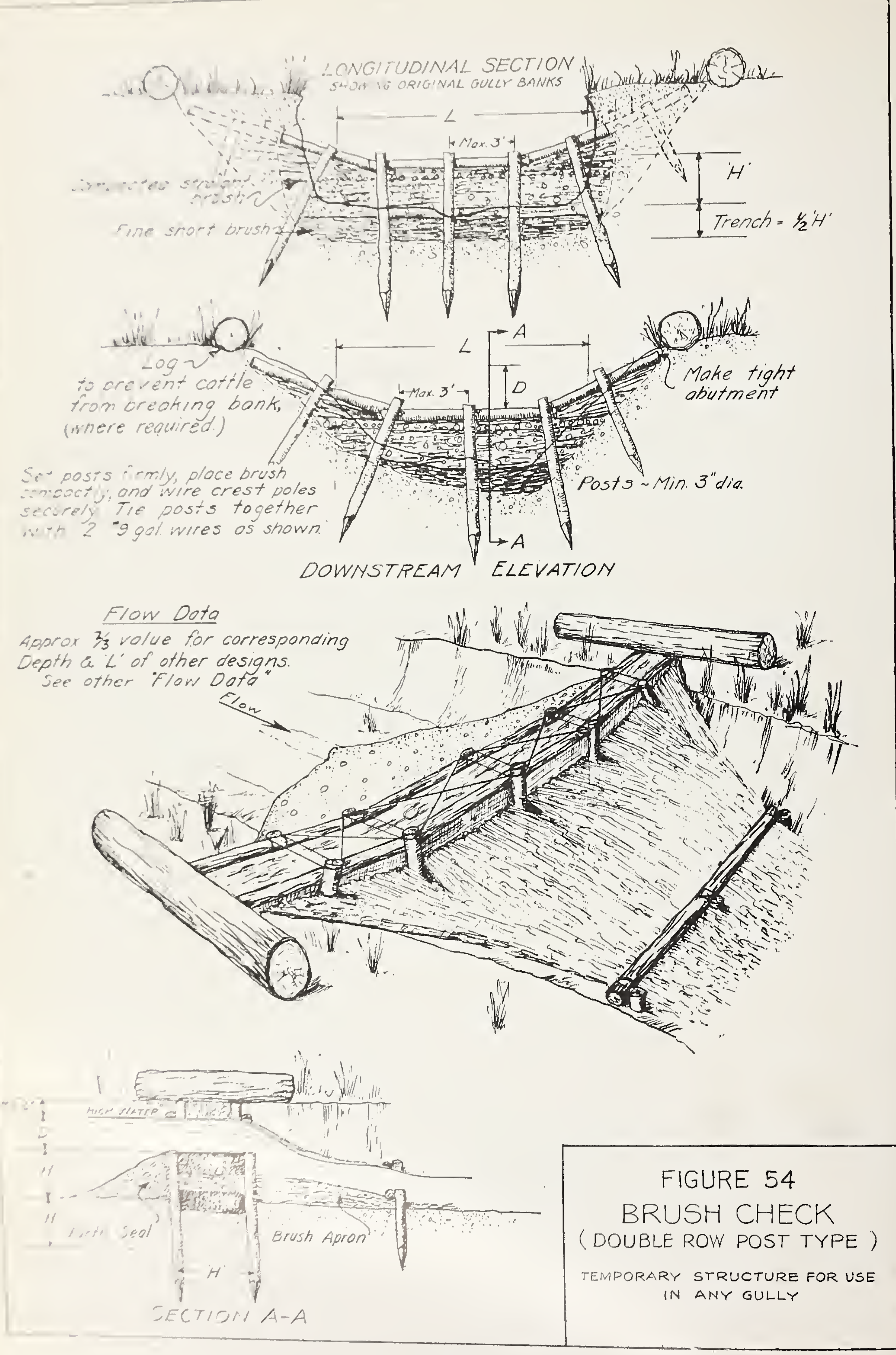


FIGURE 54
BRUSH CHECK
(DOUBLE ROW POST TYPE)

TEMPORARY STRUCTURE FOR USE IN ANY GULLY

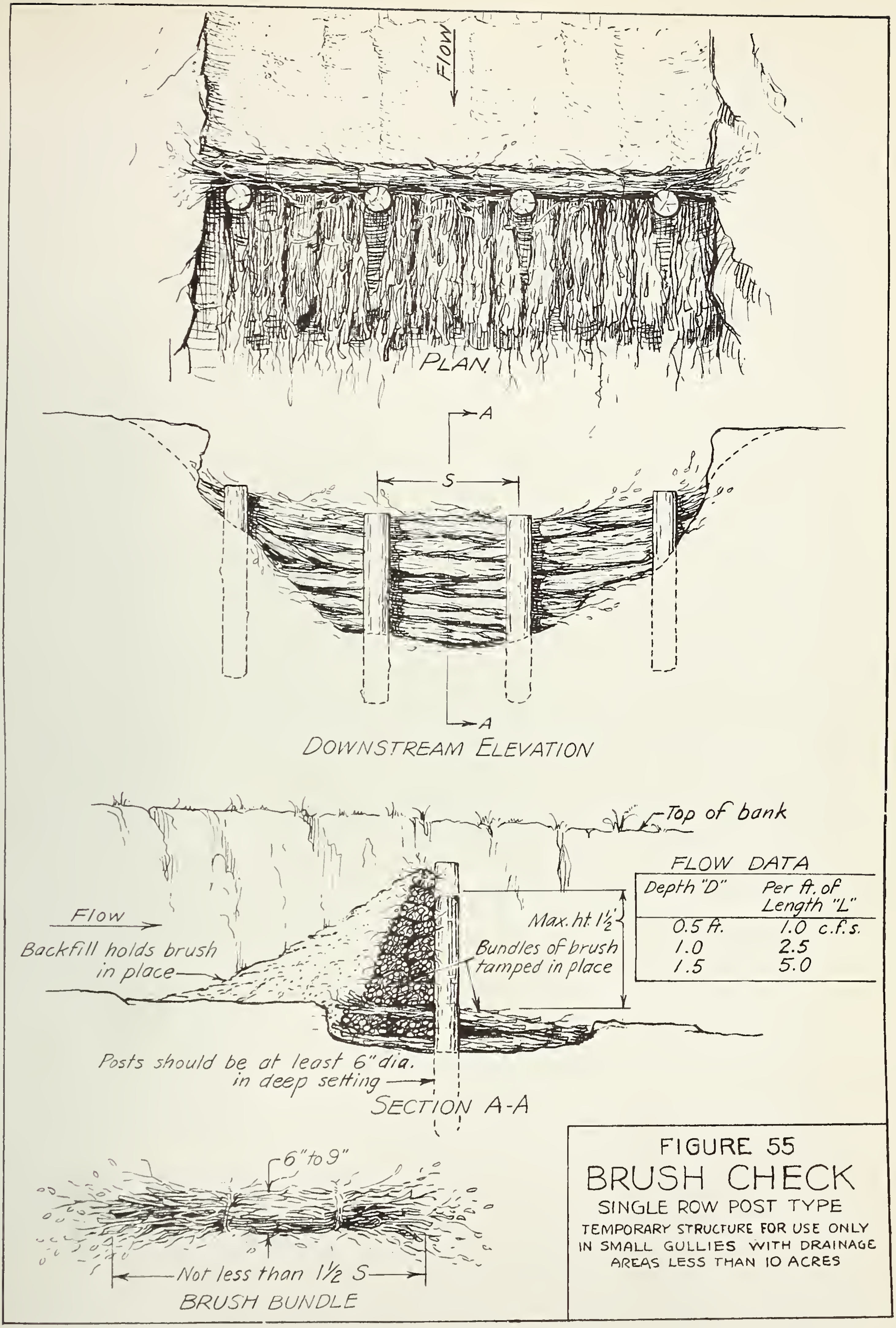


FIGURE 55
BRUSH CHECK
SINGLE ROW POST TYPE
TEMPORARY STRUCTURE FOR USE ONLY IN SMALL GULLIES WITH DRAINAGE AREAS LESS THAN 10 ACRES

Chapter V

ESTIMATED COST OF RESTORING[1] A GULLY

31. Assumed Problem.

For discussion, the following assumptions are made:

a. That it is necessary to restore a gully in a mountain meadow or valley similar to that shown in figure 56.

b. The drainage area above the meadow is 5 square miles.

c. The average annual maximum flood is 50 second-feet and the average 10-year maximum flood is 200 second-feet.

d. The meadow or valley is 2 miles long and a fourth of a mile wide.

e. The soil in the upper mile of the valley is an adobe and in the lower mile is disintegrated granite much more erosible than the adobe.

f. The gully extends along the axis of the valley.

g. The slope of the gully bottom for the upper mile is 1 percent and for the lower mile is 0.75 percent.

h. The drops or overfalls in the upper mile are 400 feet apart and 4 feet high, and in the lower mile are 600 feet apart and 7.5 feet high.

i. The distance from the valley floor to the bottoms of the drops is 6 feet in the upper mile and 12.5 feet in the lower mile.

j. The gully is 6 feet wide.

k. The gullies at right angles to the main gully have just started in the upper mile and in the lower mile have progressed about 100 feet.

l. The slope of the valley from the sides toward the gully is 3 percent.

m. Ample funds are available for a long period of time.

32. Suggested Solutions.

The method of restoring this gully will consist of control measures *a* and *l*. Consideration will be given to applying them in the following different ways:

Solution 1.

Measure *a*: The number of livestock permitted on the drainage area tributary to the valley will be reduced to allow vegetation to return more rapidly. The trough of the valley will be fenced to exclude grazing and allow the sod to regain its original strength and thickness.

Measure *l*: Loose rock checks with facing laid in cement mortar (see fig. 48) will be constructed in the upper mile and rubble masonry checks (see fig. 50) will be constructed in the lower mile of the gully. These will be constructed with crests 6 feet long and within 3 feet of the valley floor. This will provide sufficient capacity to carry the average annual maximum flood. Floods greater than 50 second-feet which occur less frequently will spread out over the banks rather thinly and for a short period. Since the trough of the valley will be fenced it can be assumed that the sod will return quite rapidly and protect the valley trough when the occasional flood overtops its banks.

Solution 2.

Measure *a*: The same as in solution 1.

[1] By restoration is meant the complete filling of a gully to its original ground level.

FIGURE 56.

GULLY IN A MOUNTAIN MEADOW, CUYAMACA STATE PARK, CALIF.

Measure *l*: Wire fence checks 18 inches high (see fig. 52) will be constructed in the bottom of the gully. As these become filled up other checks will be placed on top of the silt, thus gradually raising the gully to the same height as the permanent structures in solution 1. After the silt has been raised to the proper height, loose rock checks with facing laid in cement mortar will be constructed to hold the silt in the drainage channel.

Solution 3.

Measure *a*: The number of livestock on the drainage area will be reduced as in solutions 1 and 2, but the valley will not be fenced. There will be a tendency for the livestock to congregate in the valley and thus delay or prevent a full return of the sod.

Measure *l*: Loose-rock and rubble-masonry checks with crests 6 feet wide will be constructed as in solution 1. However, since the trough of the valley cannot be protected from grazing, it will not be practicable to flood the banks of the gully to the extent contemplated in solutions 1 and 2. Therefore, the check dams will be constructed to handle the 10-year maximum flood of 200 second-feet. This will require provision for a height of 5.1 feet of water over the crest of the check. To allow for this the checks will be constructed to within about 3 feet of the top of the gully banks and wire fence wings 2 feet higher will be extended back from the gully on each side to where the ground is 2 feet higher than at the gully. This will require wings 67 feet long on each side, since the ground slope is 3 percent.

Solution 4.

Measure *a*: The same as in solution 1.

Measure *l*: For the upper mile of the gully the same as in solution 1. For the lower mile of the gully the same as in solution 2.

33. Comparative Costs of Treatment.

The following cost figures will be assumed to include maintenance of the structures during their necessary life:

Solution 1

Measure *a*: 4½ miles barbed wire fence, at $350	$1, 575
Measure *l*:	
Upper mile 17 rock checks, at $33	561
Lower mile 7 masonry checks, at $300	2, 100
Total cost solution 1	4, 236

Solution 2

Measure *a*: 4½ miles barbed wire fence, at $350	$1, 575
Measure *l*:	
Upper mile 53 wire checks, at $8	424
Lower mile 100 wire checks, at $8	800
Entire gully 79 rock checks, at $26	2, 054
Total cost solution 2	4, 853

Solution 3

Measure *a*: No fence—no cost (grazing value not considered).	
Measure *l*:	
Upper mile 17 rock checks, at $33	$561
Lower mile 7 masonry checks, at $300	2, 100
Entire gully 24 wire wings, at $9	216
Total cost solution 3	2, 877

Solution 4

Measure A: 4½ miles barbed wire fence, at $350		$1, 575
Measure D:		
[illegible] 17 rock checks, at $33		561
[illegible] 100 wire checks, at $8		800
[illegible] 44 rock checks, at $36		1, 144
Total cost solution 4		4, 080

34. Analysis and Decision.

Solution 1 will give the quickest and most positive results. The relative merits of the other three solutions are approximately equal.

Since any one of the four solutions will effectively restore the gully and the assumptions indicate no great value to be placed upon speed of restoration, the solution having the lowest total cost will be selected. This is solution 3, which will cost $2,877 against $4,236 by solution 1. It can be readily seen from this example that the full restoration of a gully is a very expensive process which can be justified only in special cases. In general, it would be sufficient to revegetate without restoring the gully.

Chapter VI

SOIL-SAVING AND DEBRIS DAMS

35. Use.

Soil-saving and debris dams are constructed where the primary purpose is to collect and store the silt and debris in a stream channel or a gully. The term "soil-saving dam" is usually applied where the stored silt will be used for agricultural purposes. An example of this is the restoration of a large gully in a field or meadow. The term "debris dam" is usually applied when the purpose is to prevent the silt, rocks, and other flood debris from being deposited on valuable property. The collecting area has no other particular value in this case.

Soil-saving and debris dams are usually larger structures than check dams, and an important element in their location is the presence of a large storage basin above them.

From the standpoint of service and permanence, the rubble-masonry dam will be very desirable as a soil-saving or debris basin structure. In many cases it will be used as the spillway in combination with earth fill embankments.

Because of the many variables such as foundation conditions, height, depth of overflow, amount of freeboard, and so forth, the design of each structure is a problem for individual treatment, and should be handled in whatever manner has been set up by the regional offices. Under this arrangement, proper treatment in regard to such important features as cut-off walls, cross-sectional area, and stilling pool or apron, will be assured.

Where steep narrow canyons do not permit the construction of a debris dam in the channel, it is often possible to build a dike around a portion of the flood cone at the mouth of the canyon, which will serve to store a considerable amount of eroded material. Such a dike or debris basin should have a masonry or concrete spillway at the lowest point to allow surplus flood water to drain away. The interior of the basin should have a number of spreading structures to cause the flood to deposit its load in the upper part of the basin and make as much of the water as possible seep into the ground.

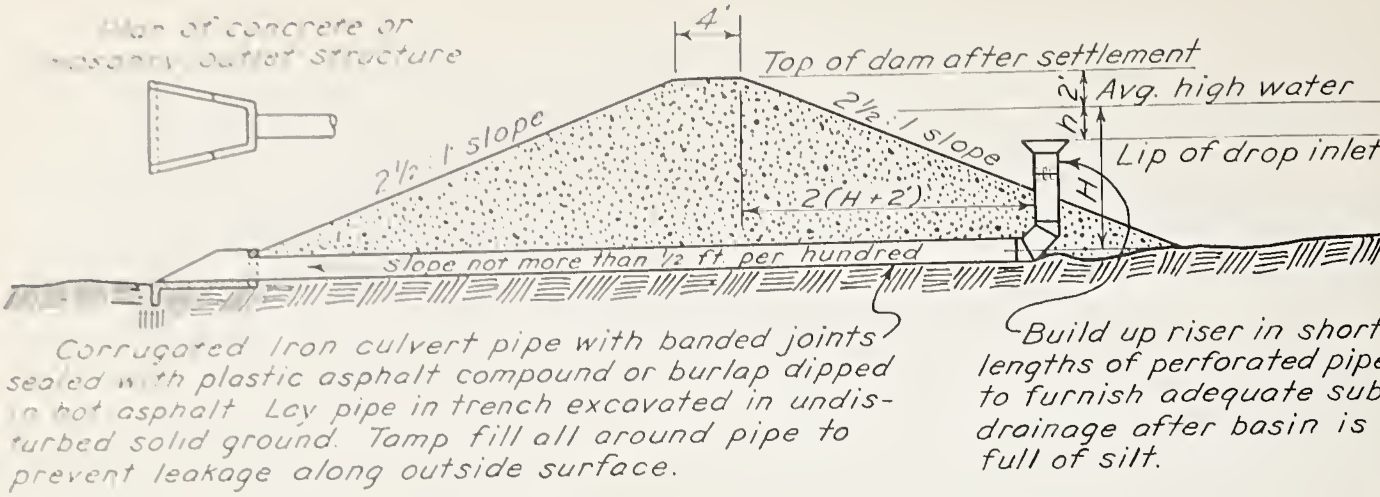
Figure 14 shows a typical debris basin; refer also to page 20.

36. Earth Fill With Drop Inlet Spillway and Auxiliary Channel.

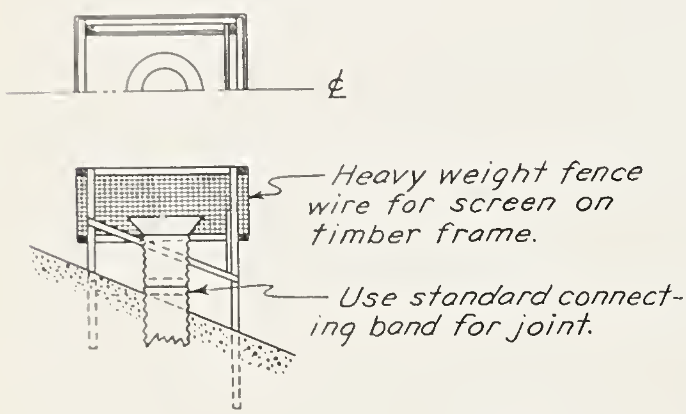
As in all earth dams, the most important feature in the design is that there be enough spillway capacity to prevent flood water from overtopping the earth fill, which usually means loss of the dam. It is not usually feasible to install a drop inlet structure large enough to handle the rare floods that may occur within a 100-year interval. Instead, an auxiliary overflow channel should be provided to carry the excess beyond the capacity of a drop inlet designed to handle the 25-year flood.

Where the natural soil is of a tight and compact nature, and in climates where a good sod cover can be maintained, the so-called broad-crested spillway channel can be used for auxiliary or emergency service. The requirements are a wide, shallow channel with a flat slope so that the water velocity will be low enough to prevent erosion of the partially protected floor and sides. The heavier and tougher the sod cover the higher the safe velocities will be, starting at about 3 feet per second for bare soil and increasing to 7 or 8 feet per second for tough sod. If the soil is not suitable because of sandy or porous nature and inability to grow vegetation, a channel lined with masonry or concrete will be required. See chapter III, sections 17 and 18, for further information on the design of these channels.

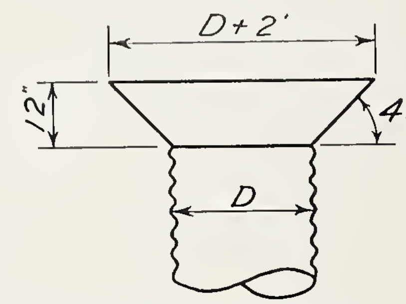
For dams that will have inlet drops from 5 to 15 feet high, culvert pipe will usually prove to be the least expensive material to use. The useful life of galvanized corrugated iron in this kind of service will probably range from 20 to 40 years depending on the nature of the soil. The basin will fill up long



TYPICAL SECTION THRU PIPE



SECTION ON ℄
Showing screen for inlet



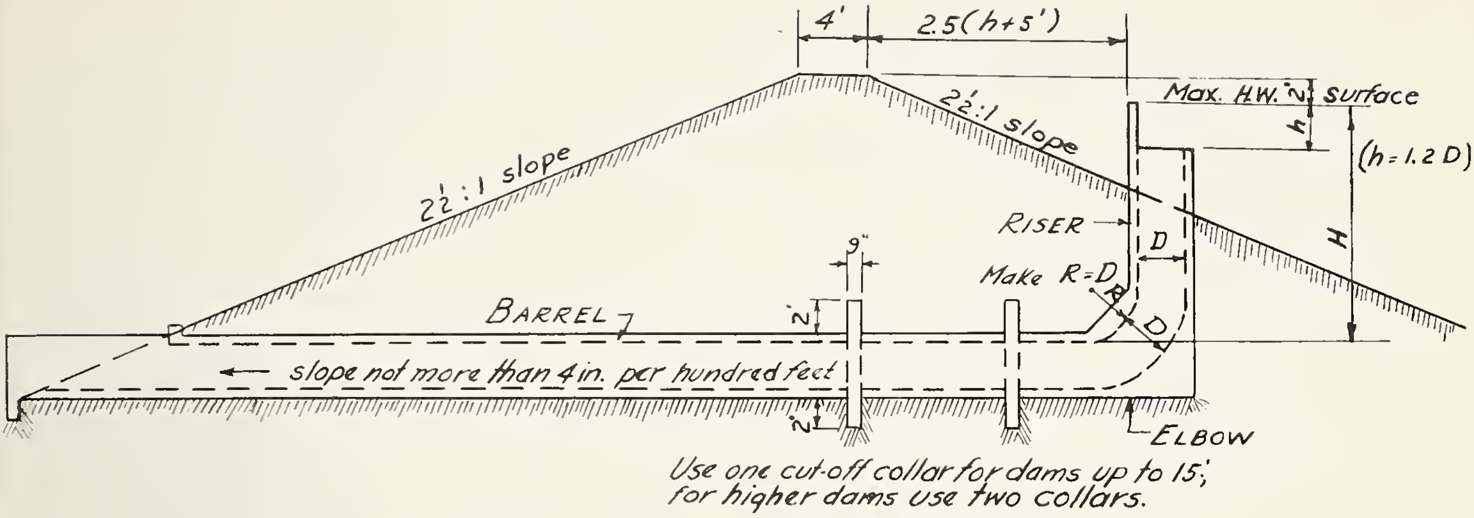
This flore increases discharge capacity but is not essential.
Discharge table below is for pipe without flare.

DETAIL OF FLARED INLET

DISCHARGE CAPACITY TABLE FOR CORRUGATED PIPE c.f.s												
Pipe Dia.	H = effective head in feet											h
	5	6	7	8	9	10	12	14	16	18	20	
12"	10	11	12	12	13	13	14	15	16	17	18	1'-5"
15	16	17	19	20	21	22	23	24	26	27	28	1'-6"
18	23	25	27	29	30	32	34	36	38	40	42	1'-10"
24	43	46	50	53	56	59	63	68	72	75	78	2'-5"
30	69	74	80	85	89	93	102	110	116	121	126	3'-0"
36	100	108	116	123	130	137	149	160	169	178	186	3'-8"
42	136	149	160	170	180	189	205	220	233	244	256	4'-2"
h = depth of water over end of pipe to give full capacity as given in this table.												

FIGURE 57

SOILSAVING DAM
EARTH FILL WITH METAL PIPE OUTLET



TYPICAL SECTION THRU DAM.

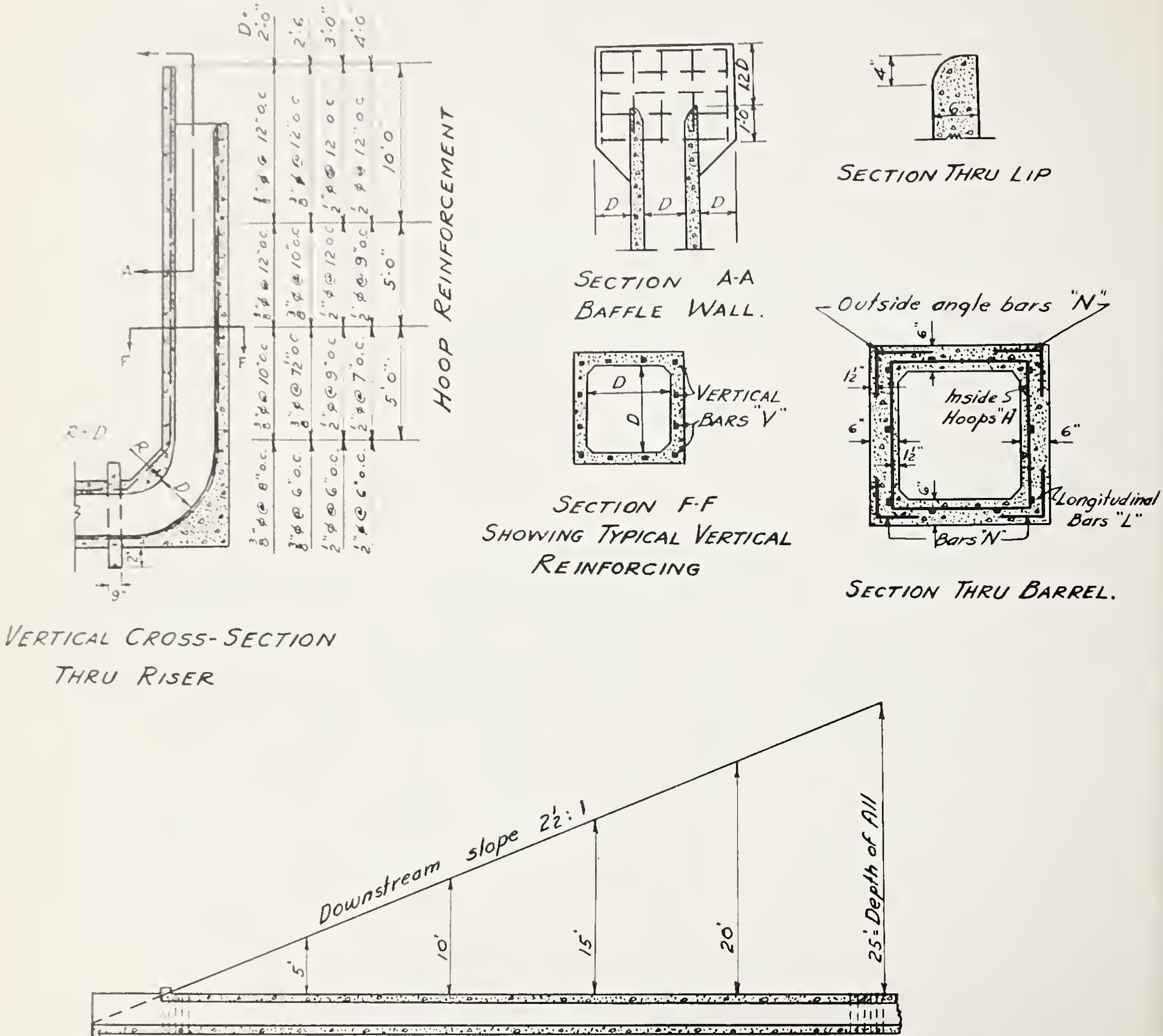
DISCHARGE CAPACITY TABLE FOR CONCRETE CONDUIT
c.f.s.

Total head H in ft.	Size of Inlet 2'x2'	2½'x2½'	3'x3'	3½'x3½'	4'x4'
10	78	120	174	234	306
12	84	130	188	255	332
14	89	139	201	275	358
16	94	147	213	290	380
18	98	155	225	305	400
20	102	162	236	319	417
22	106	168	244	331	434
24	110	174	252	343	450
26	113	179	260	354	464

SCHEDULE OF REINFORCING STEEL

Conduit Size	Bar Mark	Length	Size	Spacing
2'x2'	I&V	Continuous	5/8"ø	13"
	N	None		
	H	See	next page	
2½'x2½'	I&V	Continuous	5/8"ø	16"
	N	15"x15"	Same as Bars "H"	
	H	See	next page	
3'x3'	I&V	Continuous	5/8"ø	9"
	N	18"x18"	Same as Bars "H"	
	H	See	next page	
4'x4'	I&V	Continuous	5/8"ø	13"
	N	24"x24"	Same as Bars "H"	
	H	See	next page	

FIGURE 58



12.5'	12.5'	12.5'	12.5'	12.5'	size of conduit
3/8" ϕ @ 12" o.c.	3/8" ϕ @ 12" o.c.	3/8" ϕ @ 8" o.c.	3/8" ϕ @ 6" o.c.	3/8" ϕ @ 4" o.c.	2' × 2'
3/8" ϕ @ 12" o.c.	3/8" ϕ @ 8" o.c.	3/8" ϕ @ 5" o.c.	1/2" ϕ @ 6" o.c.	1/2" ϕ @ 5" o.c.	2½' × 2½'
1/2" ϕ @ 12" o.c.	1/2" ϕ @ 9" o.c.	1/2" ϕ @ 6" o.c.	1/2" ϕ @ 5" o.c.	1/2" ϕ @ 4" o.c.	3' × 3'
1/2" ϕ @ 12" o.c.	1/2" ϕ @ 8" o.c.	1/2" ϕ @ 6" o.c.	1/2" ϕ @ 6" o.c.	1/2" ϕ @ 5" o.c.	4' × 4'

Size and Spacing of Hoop Reinforcing Steel.
(Bars "H")

FIGURE 59

before that time, so that the drop inlet feature will no longer be required. However, some kind of surface spillway with capacity to handle all run-off will have to be provided when the pipe goes out of service.

In selecting the site for this kind of dam, the choice will usually be dictated by the gully and watershed requirements rather than by foundation or topographic conditions under the dam. Since the reservoir is to be used primarily for collecting soil rather than water, it is not essential that the dam or its foundation be particularly impervious. In preparing the base, clean off all sod, stumps, or other vegetable matter and plow the surface to give good bond between the base and the fill material. The culvert pipe should be laid in a trench excavated in natural ground. As the backfill progresses, tamp it carefully against the sides of the pipe as in all culvert installations. Use standard connecting bands and cinch bolts to join the sections together. The riser is best made of 2-foot sections above the elbow, adding additional pieces as the level of the soil deposit increases. In locations where underdrainage may be slow, standard perforated pipe can be used, facing the perforations on the upstream side. As noted on figure 57, the use of the flared lip to the riser is optional. Under some conditions, it may increase the discharge capacity 6 or 8 percent over that listed in the table.

For higher dams with a drop of 20 or 25 feet, reinforced concrete spillway structures will be found the cheapest and will also have the longest life if well built. All details of the design shown in figures 58 and 59 must be followed if maximum capacity is to be had. When the depth of water flowing over the lip is 1.2 times the width of the opening, the full capacity is realized. This capacity depends on the existence of a vacuum in the upper end of the tube, and it is therefore important that the barrel flow full to keep air from entering from below to break the vacuum. It is, therefore, important that the maximum slope restrictions shown in figure 58 be observed.

If there is danger of much floating debris in the water, it will be advisable to build a trash screen around the inlet, as shown in figure 57. This may prevent serious damage from a clogged inlet structure.

37. Earth Fill Dams With Masonry Spillways.

Where the amount of run-off is too great for a drop inlet spillway, a cement rubble masonry spillway is often used. Figures 60 and 61 show such structures as used on flood-control projects handled by the United States Forest Service in Utah.

38. Masonry and Concrete Dams.

Figure 62 shows a rubble-masonry arch debris dam constructed by the United States Forest Service in California.

Where large masonry, concrete, or earth dams are constructed, they should follow the principles of construction specified in the handbook on the Design and Construction of Forest Service Dams.

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FIGURE 60.

EARTH FILL DEBRIS BASIN WITH MASONRY SPILLWAY.

FIGURE 61.

EARTH FILL DEBRIS DAM WITH MASONRY SPILLWAY.

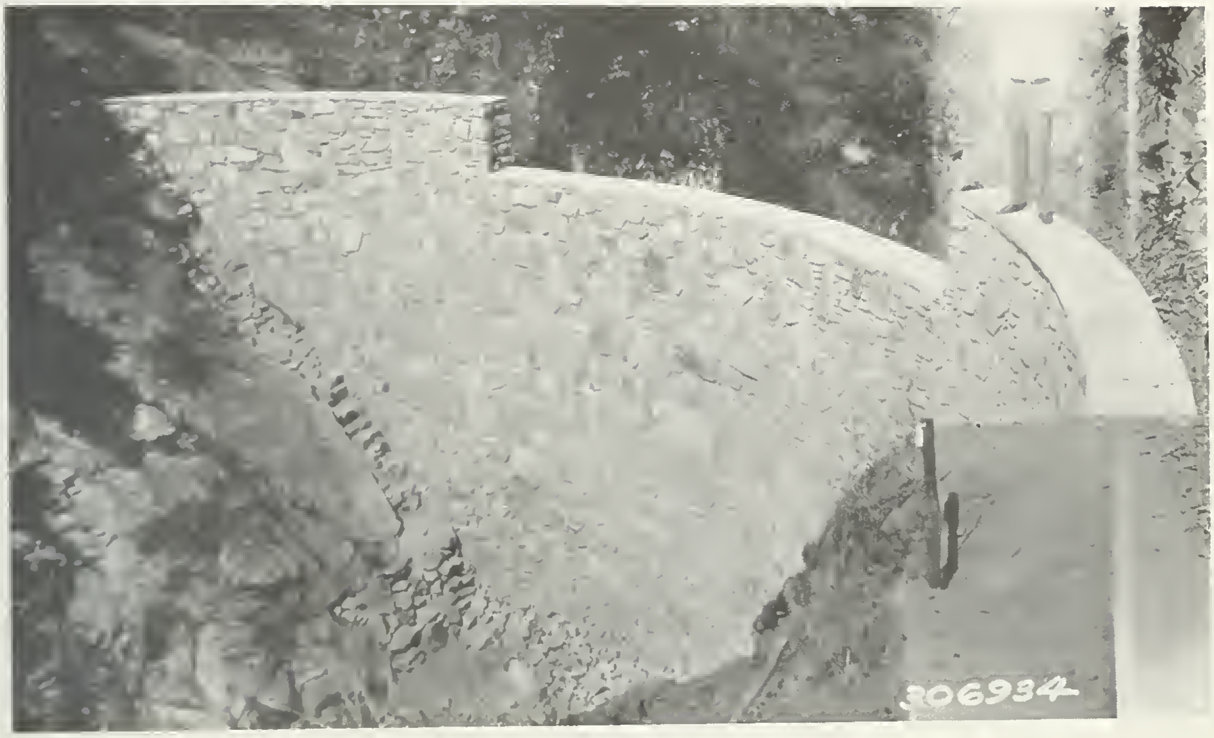

FIGURE 62.
MASONRY ARCH DEBRIS DAM.

Chapter VII

MISCELLANEOUS STRUCTURES

39. Contour Furrows.

On devegetated slopes there is little to retard the flow of accumulating rainfall, so it runs down the slopes with increasing velocity, picking up particles of soil as it goes. A method of reducing this surface-water loss is to promote absorption by collecting the water in level ditches in which it is retained until completely absorbed. From the viewpoint of water conservation, this is a very desirable condition. The reduction in surface run-off decreases erosive action and flood peaks, and the additional ground moisture aids vegetative growth and increases the ground-water supply.

A complete contour furrow system provides furrows with correct size and spacing so that all the rainfall from the most intense storms can be retained. On very steep slopes it is particularly important that the furrows hold all the water, because if they overflow there will be a break in the side wall which will concentrate the outflow and perhaps be the cause of a new gully formation. Figure 63 on page 80 shows a detail view of one of these systems on a rather steep slope. Note that cross dams have been made at frequent intervals to prevent longitudinal flow in case of a break in the furrow or poor grade alinement. The top of the cross dams should be somewhat lower than the outside of the furrow.

On moderate slopes, the spacing of the furrows can be increased and their capacity reduced so that they can be expected to overflow at rare intervals, at which time no harm will be done because settlement of the banks and vegetative recovery have put the ditch walls in condition to resist cutting. The addition of vegetation, either natural or planted, in the bottom and on the sides of the furrows is desirable because it increases the absorption factor and binds the soil against erosion.

The spacing and capacity of the furrows are two of the most important factors in the design of a system. Steep slopes on tight soils which absorb water slowly will require ditch capacities that will be needed at very rare intervals, say 50 years. As the slopes become flatter and the soils more absorptive, the frequency of storms which will cause overflowing can be shortened. The condition of vegetative growth and the speed with which it can be expected to take hold can also be considered. The object is to obstruct and delay the surface water to promote a maximum amount of infiltration and a minimum amount of damage from erosive and flooding action.

Figures 5 and 6 show a contour furrow system in porous soil on a very steep slope.

40. Ditches.

Intercepting ditches (measure *b*) are constructed above an eroded area to reduce the amount of run-off on the actual eroded area itself.

Diversion ditches (measure *m*) are constructed to divert water from a gully or other channel and carry it to spreading structures, another channel, or to a debris basin.

The following principles should be observed in their construction:

1. Provide sufficient capacity to carry the maximum probable run-off. This should ordinarily be the 10-year maximum.

2. The gradient of the ditch should be sufficient to carry the run-off without an excessive accumulation of silt in the ditch and yet not steep enough to cause cutting in the ditch.

3. Points along the ditch that are endangered by the advance of a gully from below should be protected by means of a gully-head plug.

4. The point where the ditch empties into the protected drop channel or other disposal works should be protected by means of a check dam and apron.

FIGURE 63.
PERSPECTIVE VIEW OF TYPICAL CONTOUR FURROWS.

41. Spreading Structures.

The function of spreading areas is to provide a safe disposal ground for diverted run-off, where it can sink into the soil without damage to the surface. The desirable features are low velocities of flow and a soil made porous through vegetation or by artificial means. A well-sodded area, or a wooded or brush-covered site can be used without alteration. If such conditions are not available, artificial spreading structures can be used instead. Where the arrangement is to be of long duration, trees and brush should be planted so that they will be ready to supplant the artificial structures when their usefulness is over.

Spreading structures may be constructed of any of the materials commonly used on erosion control projects. Where the amount of run-off is small, wire-netting fences, brush, logs, or loose rock may be used. For flows exceeding about 10 second-feet, the spreading structures must be substantially built of logs, masonry, or concrete. After the large stream has been broken up into smaller units, the lighter types of spreading structures may be used.

Figure 64 shows a V-shaped spreading structure of masonry for large flows. Figure 65 shows a typical system of wire-netting spreaders below a diversion ditch. Details of these structures are shown in figure 66.

To distribute the flow from a diversion or intercepting ditch, screened openings in the downhill side of the ditch can be arranged to release only part of the flow from each to give as widespread distribution as possible. In figure 66, the first opening reaches only halfway to the ditch bottom, the second one three-fourths of the way, and the last one is on the same level as the ditch bottom. The number and depth of the outlets will vary, depending on the amount of flow, the ground slope, and the absorptive quality of the soil.

The wire-mesh spreaders are built in a flat V-shape with the point of the V in line with the greatest flow to be most effective. The angle of the V should be such that the ground slope along the wings is not steeper than 1 percent. As a general rule, the spreading should only be done on areas where there is a good sod cover to prevent trouble from erosion.

The spreader wire should be a close diamond pattern or equal, preferably 24 inches wide for the larger areas and 18 inches for the others. One-half of the width is buried in a trench which is back-filled with stones, gravel, brush, or other porous material. The effectiveness of the barriers can be increased by weaving brush, straw, etc., into the wire.

After installation, the spreading areas should be inspected occasionally so that any tendency to start erosion can be corrected.

42. Brush Wattles.

Where it is necessary to treat some small barren area such as a roadside fill, or cut, or some newly completed slopes, the wattle method may be the most efficient. A complete description of this wattle method is given in the United States Department of Agriculture Circular No. 380, "Erosion Control on Mountain Roads," by C. J. Kraebel. In general, the method is to bury wattles which are composed of willows, baccharis, or other shrubs made into a continuous rope from 6 to 8 inches in diameter, in horizontal trenches which are usually about 3 to 5 feet apart on the slopes. These wattles are further supported on loose slopes by driving stakes into the banks. The wattles hold the fill in place until the vegetation can establish itself. The wattles may be aided by the planting of weeds, grain, or other vegetation. Figure 19 shows the use of brush wattles on a road fill.

Details of costs and methods of using this plan are given in Mr. Kraebel's handbook, and will not be discussed here at length. The cost of this treatment may be said roughly to be about $500 per acre, which limits its use to comparatively small areas of great importance, and particularly to where it is immediately desirable to hold the soil in place, such as areas that have been disturbed by plowing or on recent earth fills.

Figure 67 shows the construction details of a brush wattle.

FIGURE 64.

RUBBLE MASONRY SPREADING STRUCTURE WITH LOOSE ROCK WINGS.

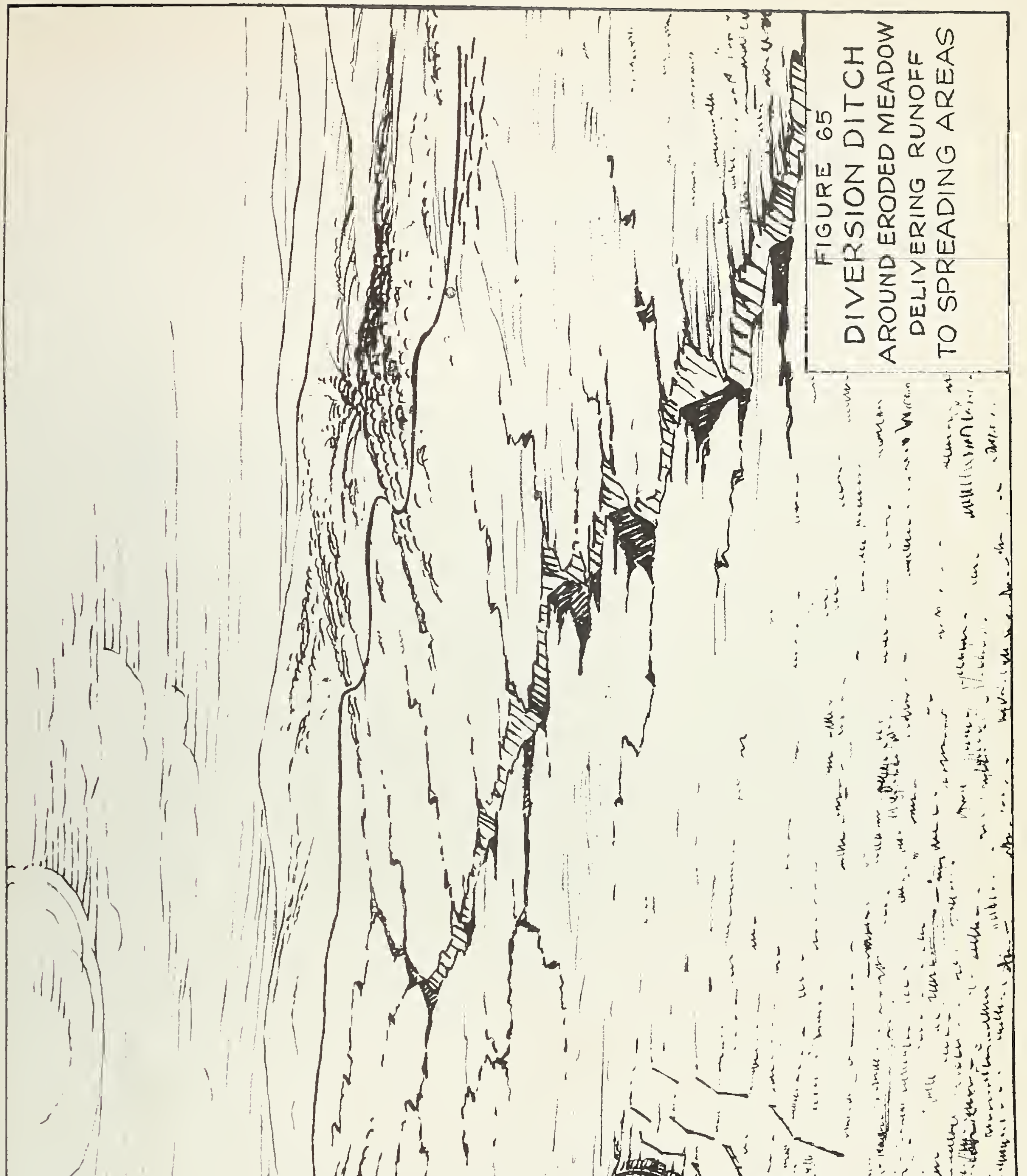

FIGURE 65
DIVERSION DITCH
AROUND ERODED MEADOW
DELIVERING RUNOFF
TO SPREADING AREAS

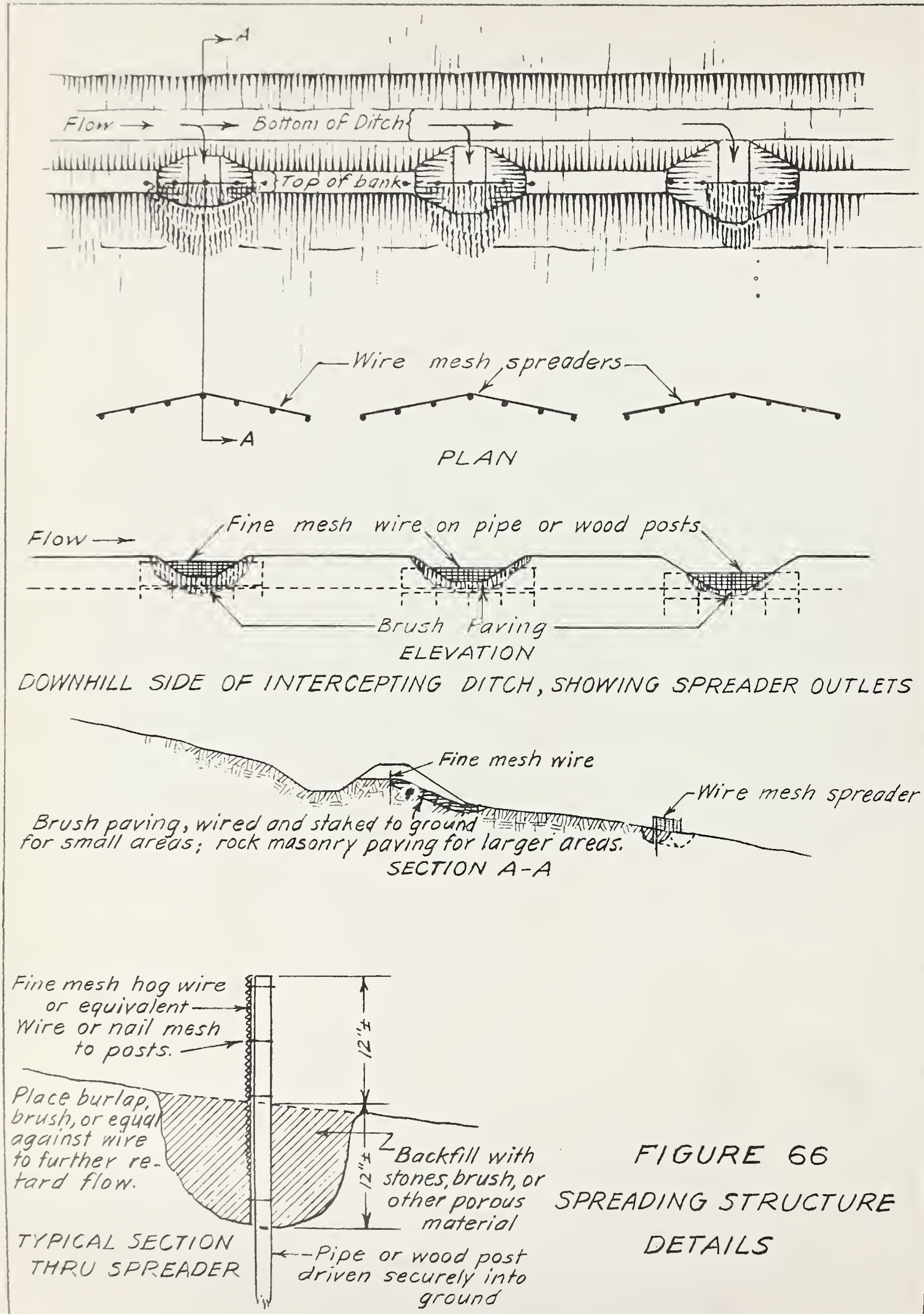

FIGURE 66
SPREADING STRUCTURE DETAILS

Figure 67.

Detail of Brush Wattle Construction.

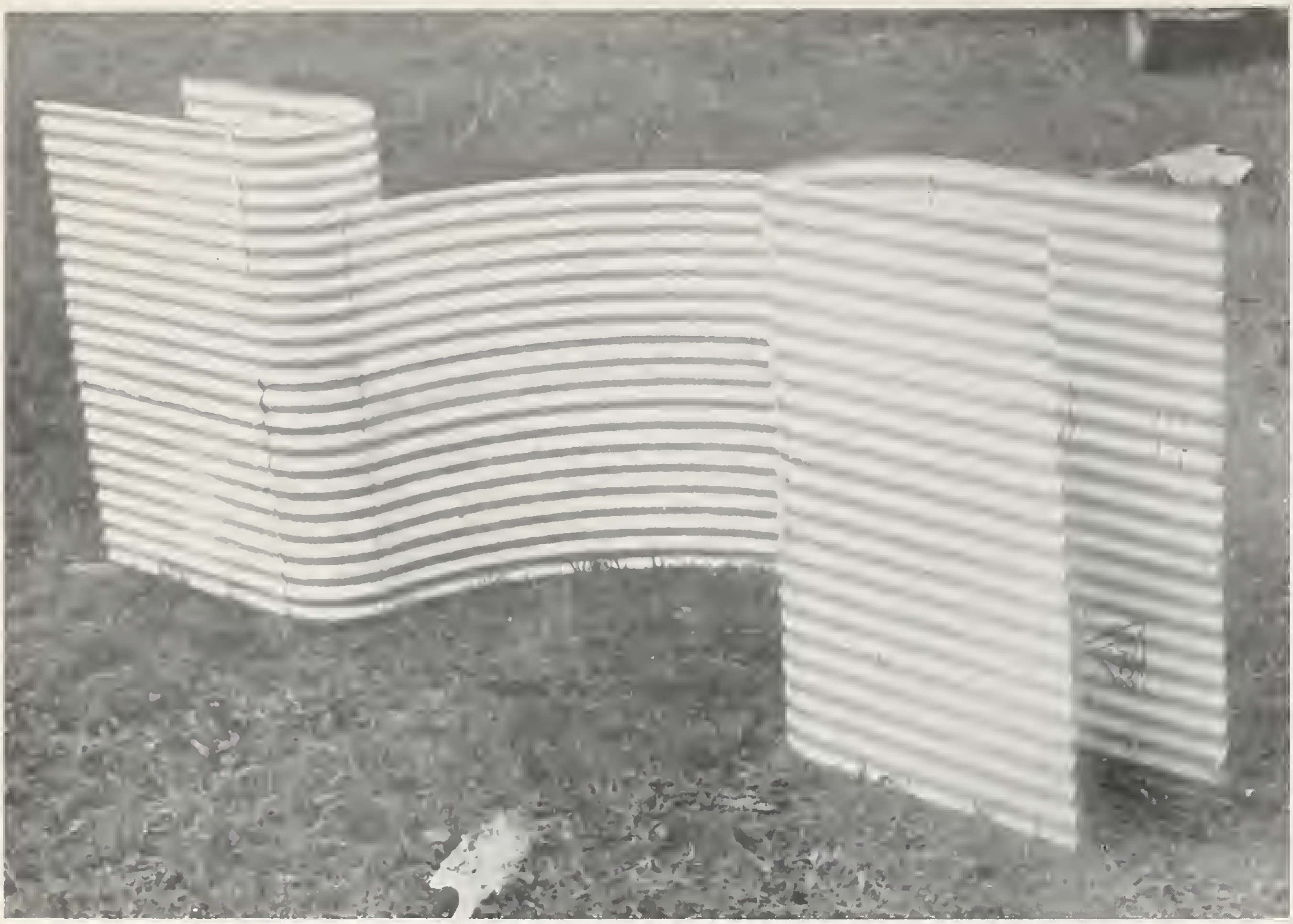

Figure 68.

Downstream Side of Arch Type Check Dam of Corrugated Iron.

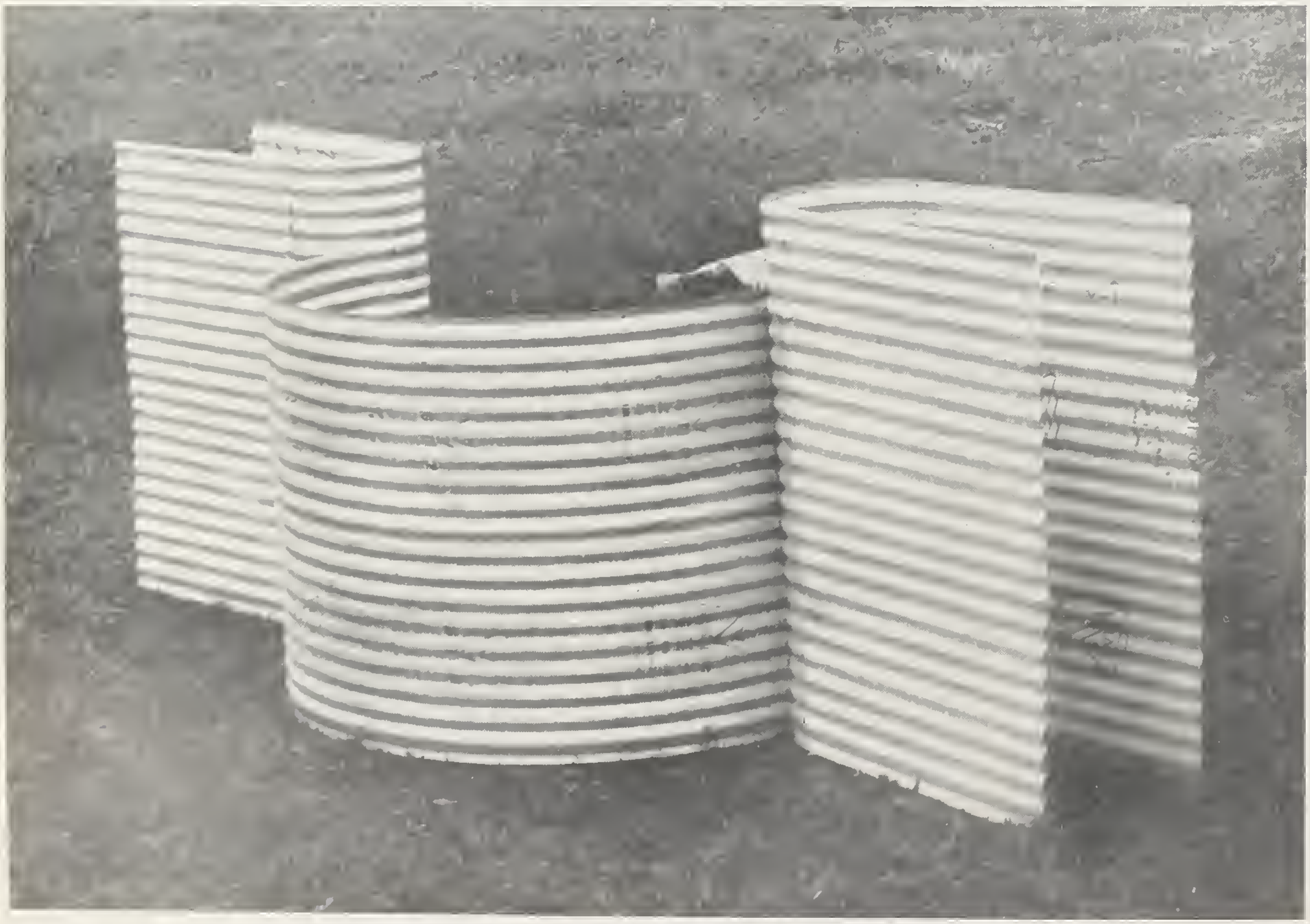

Figure 69.

Upstream Side of Arch Type Check Dam of Corrugated Iron.

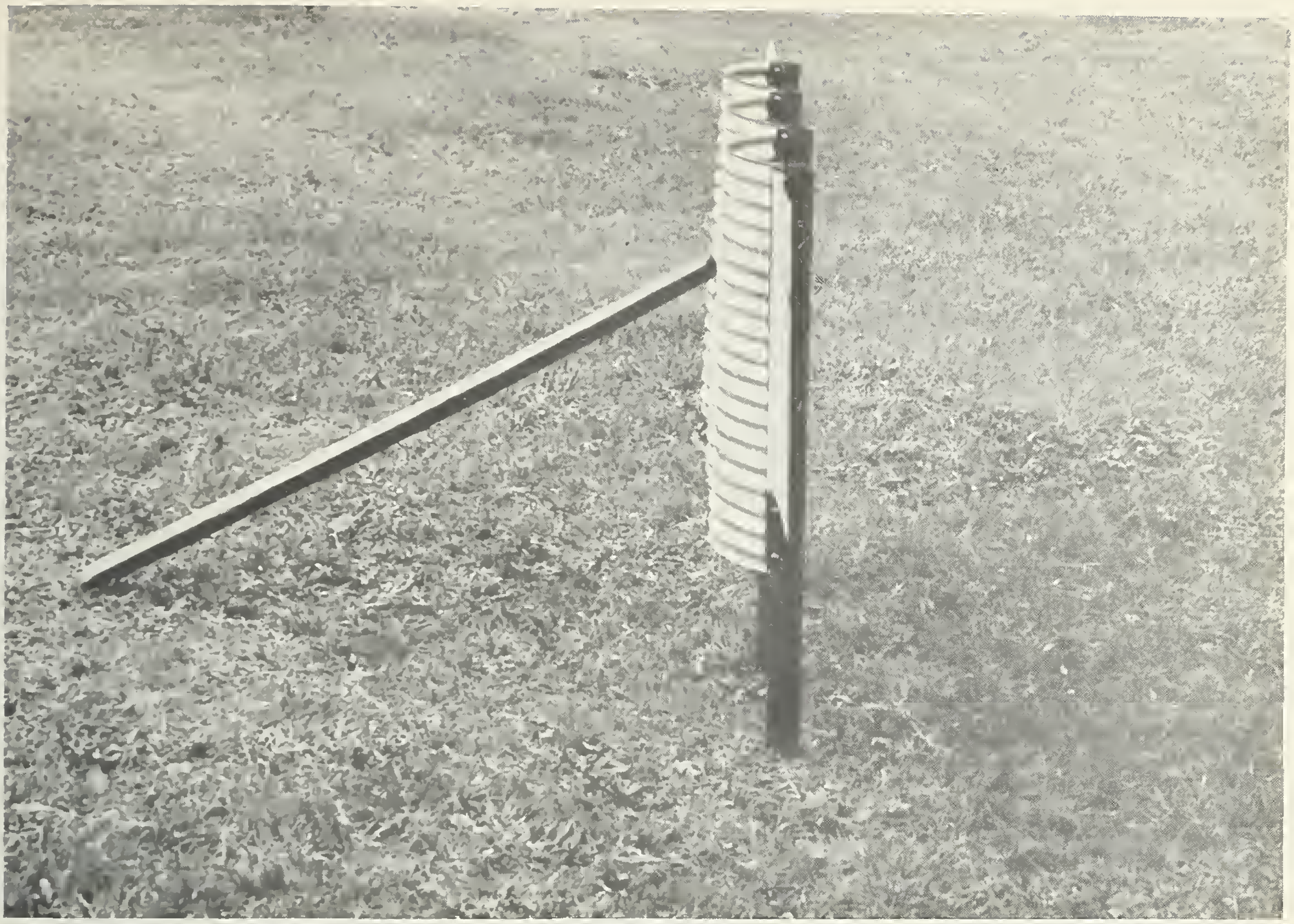

FIGURE 70.

END VIEW OF MULTIPLE ARCH CHECK DAM OF CORRUGATED IRON.

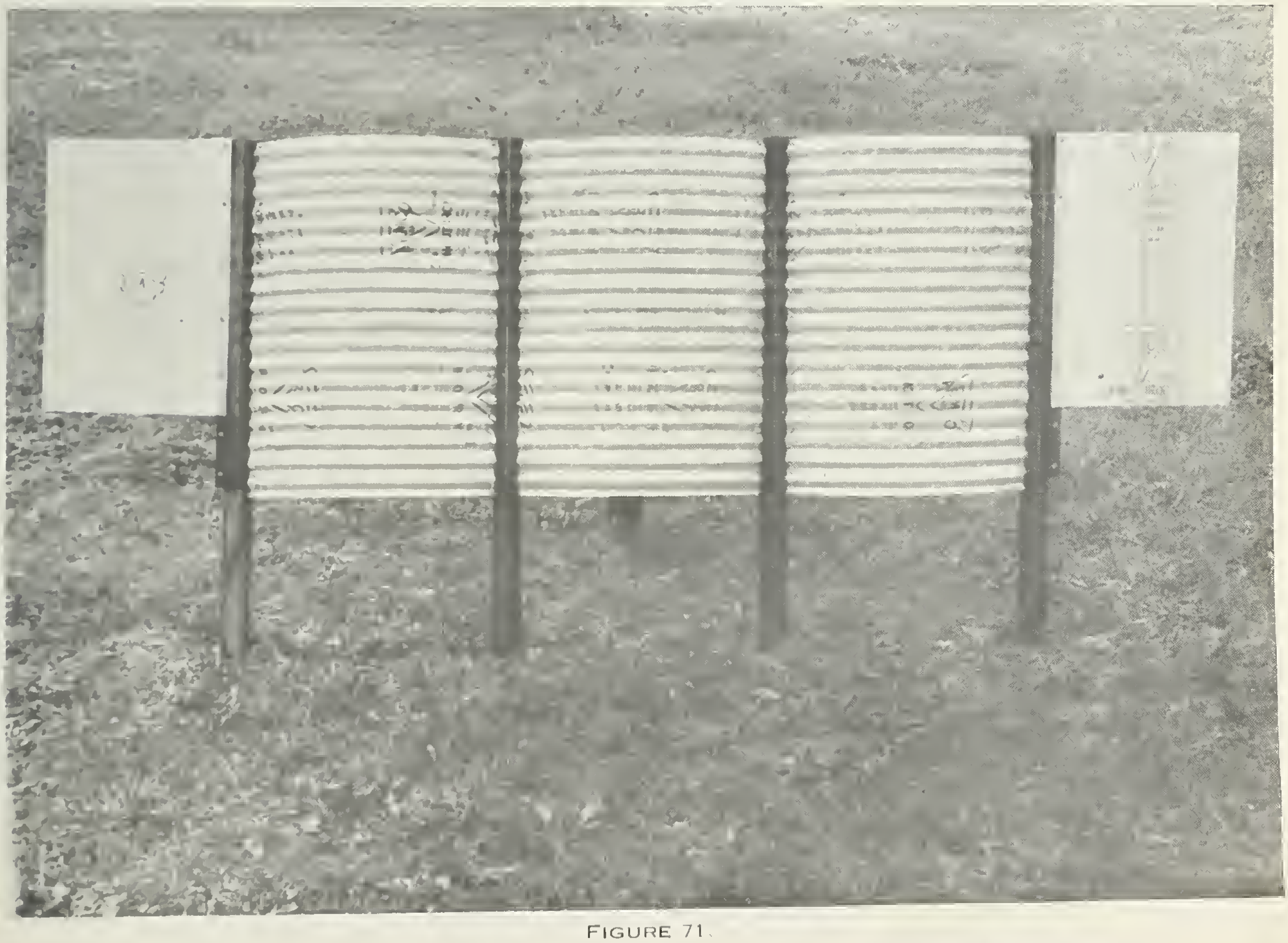

FIGURE 71.

UPSTREAM FACE OF MULTIPLE ARCH CHECK DAM OF CORRUGATED IRON.

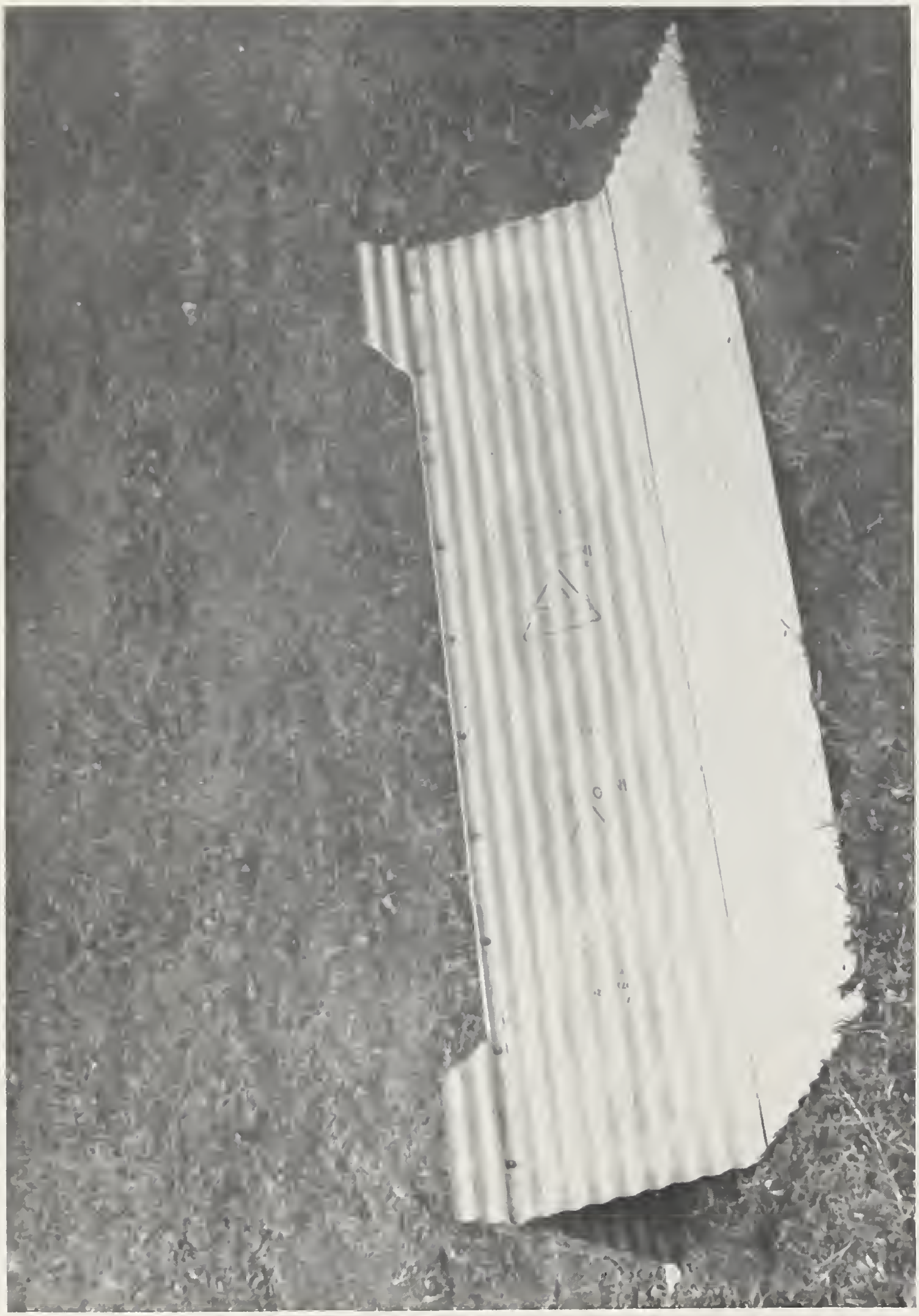

Figure 72.
Downstream Face of Corrugated Iron Check Dam With Apron.

43. Fabricated Sheet Metal Structures.

By working in cooperation with the fabricators, several all-steel check dam designs have been developed but have not been tried out in practice. They will be described briefly, as they may prove useful for special installations or for experimental work.

A single arch type structure is shown in figures 68 and 69 which give the upstream and downstream views respectively. The U-shaped sections at the ends serve as the abutments, and are to be filled with compacted soil after placing. The height and arch span can be varied to suit the requirement. Prices will vary in different localities, but for a mill at Berkeley, Calif., a price of $23.20 has been quoted for the first 2-foot height, with each additional 2-foot lift costing $17.44.

In figures 70 and 71 a three-unit multiple arch design is shown. These arches are bolted to light rail sections which are driven into the ground to serve as posts. The price quotation of a Berkeley, Calif. mill is $22.59 for a three-arch unit with two cut-off wings at a height of 2 feet. Each additional 2-foot lift would cost $17.

Figure 72 shows another type which is limited in height by the width of a standard corrugated sheet. The effective height will be about 15 inches. The photograph shows the downstream side with a sheet in place to serve as an apron, which is not provided on the other designs. In addition to the weight of backfill on the ends, the structure should be fastened to the ground by a few steel pins driven through the sheets into the foundation. A compacted ridge of soil underneath will probably be required to support the sloping faces. The price of the section shown was quoted as $23.28 at a Berkeley, Calif., mill.

If this latter type were made with a splice near the middle, it would be easier to install and more flexible for sites of various widths. In some soils it might then be jacked into place to eliminate excavation at the ends.

The prices given in this section are of course subject to change, and will vary in different regions. They are given only for comparative value.

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